VOLUME ONE • PART ONE

The History of the Filipino People

TADHANA

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Ferdinand E. Marcos

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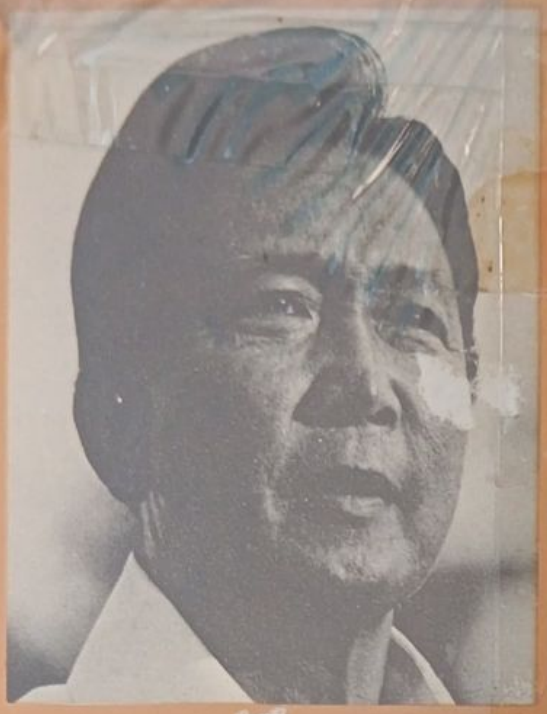

President Ferdinand Marcos

This book, "Archipelagic Genesis," is the first part of Volume One ("Foundations of Filipino Culture") of President Marcos's 19-part, four-volume Tadhana: The History of the Filipino People. Readers of this narrative on Philippine history, the most extensive ever attempted so far by any historian, are of course aware that although this is the very first book in the series it is being published only after three books of a later historical sequence have seen print.

The three books published earlier, all of Volume Two ("The Formation of the National Community," 1565 to 1896), covered the periods 1565-1665, 1663-1785, 1765-1815, respectively. While the sequence in publication seems odd, it has been necessitated by the research that the author imposed on himself so as to render a traditionally unattractive subject in a narrative both interesting and instructive.

Tadhana is the first work on Philippine history that conceives prehistory as a necessary part of history. "Archipelagic Genesis" fulfills this concept in an outstanding manner. It takes hold of a

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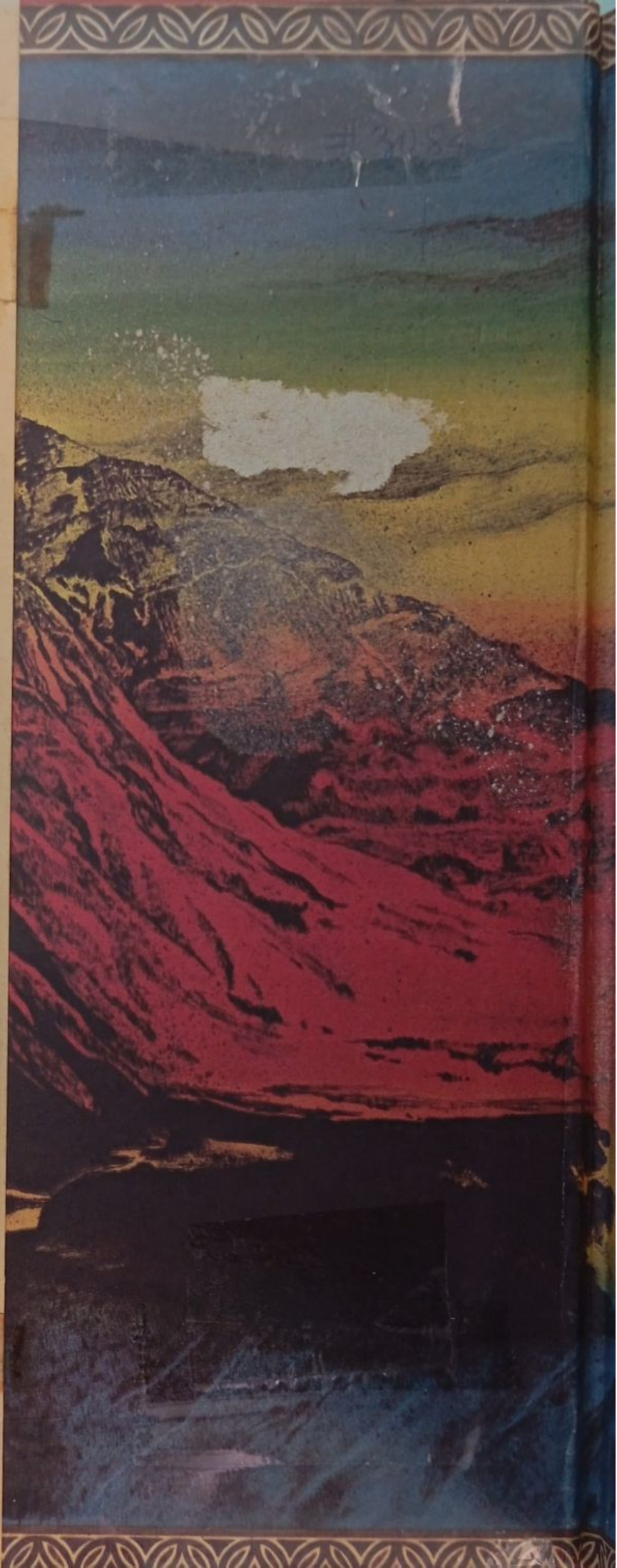

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The History of the Filipino People

TADHANA

Ferdinand E. Marcos

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VOLUME ONE

FILIPINIANA

FOUNDATIONS OF FILIPINO CULTURE

(ca. 300 million B.C. to 1565)

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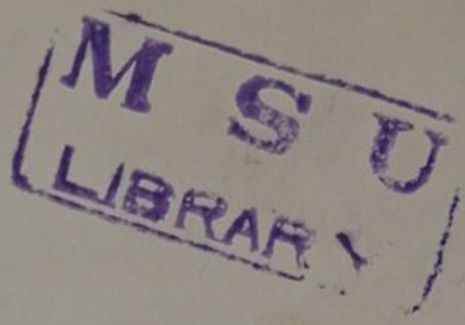
Diwata the supreme ruler and his beloved son Demowata lived in heaven. One day Demowata . . . asked his father for another place to live in. Diwata took a piece of heaven and gave it to his son . . . And Diwata called this piece of heaven banwa, *that is to say "earth." And he created a sun to light the new home of Demowata. Then he divided the earth into two by making a circle. Inside the circle he made the land, and outside was the water. He filled the land with trees, plants and animals. He named the beautiful place* Langkonoyan, *that is to say a garden of happiness. . . Then Diwata molded clay in the likeness of Demowata, but the heat of the sun caused it to crack. So he took the molded clay to the river and sprinkled it with water. And immediately the crack split the clay into two creatures which were exactly alike—the first human beings in the world.*

Pagbal dig Banwa Bo Gona Gataw *(The Creation of the World and the First Human Beings). As told by Kilino Tangkasan, a* Subano *Baliyan (Medicine man) from Sinuti, Zamboanga del Sur. Translation and comments by Virgilio Resma in "A Subanu Myth,"* Northwestern Mindanao Journal.

PART ONE

ARCHIPELAGIC GENESIS



Ka romiyonda ma ilin	*And hanged completely*
Na palao sa Songgiringa	*Are the hills of Songgiringa*
Ka miyarunding a barat	*It is shielded now by a storm*
A bugabong sa Dansalan	*That roars as it dashes,*
Ka miyabangkawit i lin	*And it has changed*
Na layagun a Bumbaran	*Far off Bumbaran.*
Ka miyagayao riganda	*For struck now*
I karagandang o kunug	*Nature's forces*
Na so kini dansal iyan	*And as they came,*
Ko kadaya o marandang	*To this wide place*
Na miyakapagudara	*They clashed*
So dagoong go so linog	*The storm and the earthquake*
A mini awong a kunug	*And the sound reverberated*
So dandan o pagilidan.	*Into all the places around.*

—Bantugan Bayok.
Translation by Abdullah Madale

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To the Filipino People

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THE PHILIPPINES IN THE REMOTE PAST

The history of any human society comes after an unimaginably long process of evolution involving the entire universe. Before written records of man's social nature began to differentiate one tribe or race from another, all matter shared a faceless, volatile existence. From the mysterious "soup" of which the early universe consisted to the hard material of the planets and finally to varieties of life, all things were bound in a common voyage through thousands of millions of years across interminable space. The notion of history came to man only when distinct differences became perceivable as particular races and communities in this huge retinue through time and space stepped off, as it were, in various directions to chart individual destinies.

Particularization itself as the immediate predecessor of every national history comprises a distinct process of evolution. Part of this process is the formation of the setting upon which a par-

ticular national history would be laid. On the larger canvas of the universe the picture that this process evokes consists of galaxies and constellations flung here and there, perhaps by a combination of accident and physical laws, through a limitless abyss. On the lesser scale of the planet earth, the process of particularization comprises the evolution of continents and islands, the homes of various groups of men themselves slowly evolving into distinct societies.

The history of the Filipino people would take place on one such distinct setting.

The beginnings of this history, the story of the co-existence of a people and an archipelago, lie far beyond the earliest songs and chronicles celebrating life, as racial memory recalls it, upon these islands. The home of the Filipino people has yielded to recent generations a geological record in some ways more exciting than oral traditions or artifacts, such as utensils and tools associated with tektites that fell some 700,000 years ago. The Philippine setting, the essential physical element of the State, formed and grew through a span of time which reached farther into the past. In that immense period, which reduces recollected human existence in the archipelago to a heartbeat, the land and seas, the mountains, plains and streams were formed and life stirred in plants and animals.

Fortunately for modern man, it has become possible, at least to some extent, to "read" the record that those dark and distant eons left of themselves. It is a record, however, that consists not of the handy and convenient script of man but of the tracks of nature in evolution or in upheaval. By means of the stars, the galaxies and constellations in the sky, we are now able to begin to comprehend the character and composition of the universe, including its beginnings which would otherwise have been lost forever in the deep recesses of time and space. From their arrangements in the enormous world about us and from the chemical elements distributed in once puzzling patterns in those stellar objects, in meteorites and in rocks, we discern a story of the forbidding past.

The evolution of the earth and of the Philippine archipelago before man appeared on the planets is thus recorded in the soil and rocks; in the remains of life that have lain buried in them

for countless millenia; in the chemistry and distribution of the rocks; in the magnetic patterns of the seafloor and the intensity and movement of heat from the interior of the earth; and in the compositions of the oceans and the atmosphere. Geologic events and environments of the past may also be glimpsed through processes taking place in the present. Today's earthquakes, the distribution of volcanoes, oceanic ridges and trenches, and changes in the composition of rocks in the earth's interior are likewise part of that continuing record, phenomena which man could seek to explain and in so doing contribute some more to the unravelling of the past.

This particular method of attempting to recapture the past is based on the principle known as *uniformitarianism*, which conceives the present as the key to the past. The principle recognizes that long after they had ceased to manifest themselves directly, certain natural conditions reveal themselves again by means of the peculiar traces they leave behind, which then become their identifying marks. For example, coral-bearing rocks such as limestone existing today in temperate regions far from the sea indicate that in the past tropical seas covered the areas where these ancient reefs are found. The presence in these ancient reefs of traces of life-forms now extinct also permits a glimpse of the environments in which these early varieties of life thrived. The principle of uniformitarianism, introduced in 1795 by James Hutton of England and popularized by John Playfair and Sir Charles Lyell during the 19th century, has been fruitfully applied to studies of the Philippines and continues to this day to facilitate attempts by Filipino and foreign earth scientists to obtain more knowledge of Philippine geology. These men of science have thus been led to read Philippine pre-history in the record etched through the ages upon the rocks.

This first part in the series that attempts to discover the roots of the Philippine nation is a layman's account of the origin of the Philippine archipelago based on such scientific effort to decipher the past. Although the topics covered in this part are not ordinarily the concern of historians, many of the events that took place in the geologic past are relevant today and will quite likely have similar value in the future. Energy and mineral resources are part of the national patrimony, and government planners today see in them increasing importance in national

development. These resources took form during the period covered here; their presence in vast quantities in the Philippines has been recognized by ancestral Filipinos, by Chinese chroniclers, and by the colonizers who subsequently came to these islands. Today, many of these resources—chiefly oil, coal and geothermal energy—are being drawn from the earth to keep Philippine progress in motion. The well-being of the nation depends to a large extent on the development of these primeval indigenous resources.

The archipelagic character of the Philippines has been an essential element in the cultural growth of the nation. The multitude of islands comprising our environment possess characteristics which they share with the settings for a few other national communities in our neighborhood, like Indonesia and New Guinea. In such tropical island-sea environment evolves a culture quite unlike that which thrives in continental and land-locked nations. In the archipelagic environment men must live with an endless coastline and bear up with a nightmare that this geographic feature creates, a constant, nationwide exposure to pirates, smugglers and aggressors. This extreme peril is compensated, however, by the breathtaking scenery offered by a coastline that rings the entire land, and by the easy growth of external trade.

The tropical environment which the Philippines enjoys has furthermore supported diversity, abundance and heterogeneity. Thus, in the tropical archipelagoes of the Western Pacific, there have evolved over the centuries a wide variety of life forms. While thus nourished in the common amniotic sac of the tropics, social groups nevertheless for long periods grew independently of others. Locked in their own corners of the archipelago by dense forests, mountains and seaways, they developed diverse cultures and languages.

The islands strewn around our part of the Pacific also possess other features in common, such as volcanoes and earthquakes, so that in the Philippines as in the others periodic manifestations of intense volcanic activity are part of the environment in which men, in the past and in the future, must live. Thus, church builders in the Philippines during the Spanish period learned to adapt their construction methods and materials to this characteristic of our environment. Today, designs for dams and power

plants are drawn likewise with particular attention to the threat of frequent or intense earthquakes.

Though thus regarded as a potential source of catastrophe, volcanoes are also associated with beauty and mystery. Numerous legends about Philippine volcanoes reflect their majestic or preternatural qualities. Some of these volcanoes, notably Makiling and Arayat, are for instance celebrated in legend as the abodes of gods and goddesses. A volcano in Mindanao, Mount Apo, which is also the highest mountain in the Philippines, has with its sulphurous emanations and occasional eruptions inspired a charming mythology among the Bagobos, who have lived in its neighborhood since ancient times. To this day, these tribes regard the volcano in fear and awe as the dwelling place of demons whom they call *buso*. Mayon Volcano, whose periodic eruptions have caused great destruction in Albay, has on the other hand fetched praise from worshipful brochure writers as "the world's most perfect cone."

In addition to witnessing these and other aspects of Philippine geology and geography, this attempt to revisit the distant past will also strive to provide some understanding of how the Philippine environment evolved. This environment, with its perils and bounties, acquired its present attributes over a period covering hundreds of millions of years. The complex landforms and the archipelagic environment that produced and supported varied species of life are the result of geologic events which took place through such awesome span of time. Although the Philippine archipelago shares common features with neighboring land areas, it also has unique characteristics derived from the peculiar location of the Philippines at the western edge of the Pacific and the Australian landmass.

Among the diverse ecological communities that developed in this section of the planet there evolved plants and animals unique to the Philippines. Industrialization and modernization have begun to disturb the ecological conditions in which these Philippine wildlife thrived, endangering plants and animals peculiar to our environment. In this attempt to reconstruct the past from geological records, it will be possible to see which plants and animals lived in the environment of the early Filipinos. We will also glimpse changes in Philippine life as they took place during the prehistoric times. This opportunity to see the past in the process of

evolution is important, for an appreciation of how the past contributed to the present would give man now and in the future some of the competence and the respect for nature that he needs to endow himself with habitable surroundings.

To organize this record of the origins of the Philippine archipelago as part of Tadhana's first volume, "The Foundations of Filipino Culture," information was drawn from published and unpublished material. Of the new information, much was obtained from facts and conclusions yielded by the intensive oil exploration effort that has been undertaken in the Philippines since 1973. I have also benefited from preliminary drafts of a report, "Geology of the Philippines," being prepared by the Philippine Bureau of Mines and Geosciences. Explorations for energy and mineral resources have uncovered new grounds in Philippine geology. It must be stated at once, however, that there are until now many gaps in our knowledge of Philippine geology, so much so that some concepts concerning the origin of the archipelago are themselves still evolving. With the vast amount of information that has become available in the last few decades, however, the general framework of our knowledge of geology is now firmer than it was in the past.

The study of Philippine geology drew livelier interest during the period of American colonization, but it had commenced and even achieved a respectable place long before this period of Philippine history. A dissertation for a Ph.D. degree submitted by I-chi Hsu to Washington University in 1971 therefore undermines the truth about geological studies of the Philippines, creating the wrong impression by declaring that "in the last year of the 19th century, Becker (1899) published the first paper on the geology of the Philippines." To correct this inaccuracy, which leads one to believe that earth sciences in the Philippines began only during the American occupation, it is now necessary to review the development of earth sciences in the Philippines before the 20th century.

As their myths and legends clearly indicate, even early Filipinos took profound interest in cosmogony, in the origin of the earth and sky, the sun, moon and stars, the beginnings of land and sea, of mountains and lakes. Anthropomorphic elements are common in these narratives recounting, with the uncanny intuition of ancient man, how matter and life began in the Philippine

environment. The Nabaloi people of Benguet, for instance, confidently explain the origin of the sulfur springs in Daklan and the gold mines in Benguet. Their legend about the latter, in particular, exhibits a charming primitive wisdom. In the legend, an old patriarch, Otot, was buried on a cliff by his son, Bangan. On the grave a plant of golden color grew rapidly; on the tenth day fruits ripened on its branches, and Bangan, who alone could pick them, found each one to consist of gold. The roots of the tree became the gold in Suyok; the base of the trunk, the gold in Tabio; the top of the trunk, the gold in Antamok.

From the legend one may glean that the ancient Filipinos were aware of the veinlike pattern of gold in the ground and that they had marked in their own time the mining districts in Benguet. The antiquity of mining is also reflected in place names such as Gambang, a name for copper in Benguet; Balatoc, the word for gold in the dialects of northern Luzon; Mambulao, from *bulao*, the Bicol word for gold; Paracale, referring to excavators of the trenches used in placer mining; Batobalani, a Filipino word for magnetic iron ore; and Uling, coal. Place names referring to volcanic activity, such as *mainit* (hot), *magaso* (smoking), *caua* (cauldron) also indicate early Filipino awareness of volcanism.

Observations on earthquakes and the development of mineral resources in the Philippines are coeval with the development of geology in the West. In 1669, Nicolaus Steno, a Danish physician in the court of the Duke of Florence, published *De solido intra solidum naturaliter contento dissertationis prodromus*. In this book, Steno demonstrated that tonguestones, objects with roughly triangular shape found in the cliffs of Malta, were similar to sharks' teeth. These stones, along with sea shells and other remains of marine life discovered in rocks hundreds of meters high and away from the sea, indicated that in the past these rocks lay in sea water.

The studies of Steno on layers of rocks in Tuscany led to the formulation of three basic laws of geology, namely, superposition, original horizontality and lateral continuity. These laws concern rocks formed from the consolidation of particles deposited in basins, such as lakes and seas. Within the basin, the rocks stand layer by layer, the layers in the bottom having been deposited first and those on the top coming last. Hence the law of superposition.

The layers are originally deposited in a horizontal position; tilted layers therefore indicate that at some point earth movements disturbed the original horizontality. Within the basin, the layers normally have lateral continuity, so that if layers today are abruptly truncated, the discontinuity is ascribed to erosion or to displacement of the layers by structures known as faults. These are fractures in rocks caused by a violent or powerful movement.

The three fundamental laws resulting from Steno's studies marked the beginning of systematic reconstruction of past geologic events. During the decades prior to the formulation of these laws, earthquakes and volcanic eruptions in the Philippines were described by Spanish observers. Three volcanic eruptions in 1641 are recorded in a report of the Society of Jesus published by Raymundo Magisa. Four years later, more earthquakes occurred in the Philippines, descriptions of which were published in 1649 by Alonso de Paredes.

Mineral and geothermal resources are likewise of public knowledge even in this early period of Philippine history. Official correspondence in 1643 report the abundance of gold in Camarines Norte. By 1671, Laguna was already famous for its hot springs and in 1727, the area where these proliferated was named Los Baños, after the roman baths constructed there.

At the turn of the century, the organic origin of fossils established by Steno became widely accepted. Fossils from the Philippines, along with minerals and bivalves, are discussed in a work of George Joseph Camel published in 1706. In the middle part of the 18th century, more volcanic eruptions and earthquakes visited the Philippines. Father Melchor de San Antonio gives an account of the 1743 earthquakes in Tayabas (now Quezon) and Laguna. The eruptions of Taal Volcano in 1749 and 1754 are reported in detail by Fr. Francisco Buencuchillo. The Boletin Oficial of 1756 reports the eruption of 1754 and the earthquakes of the same year. The 1766 eruption of Mayon is reported by the governor of Albay in 1767. Towards the later part of the 18th century, in 1781, an expedition of the Royal Academy of France measures gravity. Also in this year a license to exploit the iron deposit in Santa Ines, Morong (now Rizal) is granted by the Spanish crown to Doña Isabel Carreaga.

An increasing number of papers on earth phenomena, geology and mineral resources, rocks and fossils of the Philippines ap-

pears in the 19th century, many of them reflecting the popular concern over earthquakes and volcanism. In 1814, Yldefonso de Aragon reports on Mayon Volcano, whose eruption that year buried many areas, such as Budiao where coconut trees were engulfed by lava up to their crowns, and Cagsawa where only the church steeple is visible today. Twelve thousand people perished in this eruption. Other eruptions of Mayon, in 1894 and 1897, are reported by Miguel Saderra Maso and Jose Corona, S.J., respectively.

In 1856, eruptions gave birth to the volcanic island of Didicas. N. Wood reports in *Nature* the birth of the new volcano in 1871. Earlier, in 1843, Alfred de la Marche had written two relevant papers, one on the hot springs of Los Baños and Taal Volcano and another on Taal Volcano. In 1861 and 1862 Francisco Antonio Llanos, S. J., wrote on the geology of Mount Arayat in Pampanga. The same Jesuit scholar recovered a meteorite in Pampanga and described the object in 1862. Six years later, Gabriel Auguste Daubree would show that the meteorite found by Llanos was a chondrite, a meteorite containing spherical shapes called chondrules.

Chemical analysis of the products of volcanism has been consistently undertaken. In 1814, Francisco Peralta analyzed volcanic ash in Albay. In 1876, an analysis of the thermal water of Taal and Los Baños was reported by Don Jose Centeno y Garcia. In the report, the water composition of Los Baños appears as follows:

Calcium chloride	60 grains
Magnesium chloride	2½ grains
Sodium chloride	26 grains
Sodium sulfate	4½ grains
Iron oxide	½ grain
Insolubles (silica)	8 grains

Measurements of water temperature show a temperature of 84°C. In Taal, the water of the interior lake is reported to have the following composition:

Sulfuric acid	2.98 weight %
Hydrochloric acid	3.16 weight %
Iron oxide	1.0 "
Silica	1.94 "

Magnesia	9.2	"
Lime	0.08	"
Soda	1.02	"
Water	90.52	"

Centeno y Garcia also records the Tiwi hot springs as having a temperature of 108° C.

One of the scientists who wrote on Philippine volcanoes and earthquakes, Ferdinand Blumentritt, the friend of Dr. Jose Rizal, wrote a series of papers on these topics from 1880 to 1885. A monograph on earthquakes and volcanoes of the Philippines was published by Alexis Perrey in 1860. Other writers who observed Philippine earthquakes are G. de Berard and S. Kneeland, both of whom wrote on the 1852 earthquake in Manila; Enrique Abella y Casariego, who described the earthquakes in Luzon in 1892; and Father Miguel Saderra Maso, S. J., already cited, who wrote a monograph on the seismology of the Philippines in 1895.

In addition to the interest in earthquakes and volcanoes, there has also been an extensive search for mineral wealth. Ancient gold and copper production in the Philippines was augmented by the discovery of the deposits in Mankayan, Benguet in 1833. Centeno y Garcia in an 1876 report speaks of 24,249 quintals of copper produced in Mankayan between 1864 and 1874. Carl Zerrener (1869) analyzes a copper-bearing mineral from Mankayan and Albin Weisbach (1876) introduces the name *luzonite* for this mineral, after the island of Luzon.

Besides copper, gold and iron, other metals were discovered in the Philippines during the 19th century. Father Justo Azofra reports the presence of mercury in Dumarao, Capiz in 1819. In 1848 the Inspector of Mines records the presence of lead, antimony and sulfur in Casiguran, Albay. Coal in the Bicol peninsula is reported in 1842. Antonio Hernandez, in 1854, writes about coal in Cebu and elsewhere in the Philippines; Centeno y Garcia, thirteen years later, also writes on the same mineral.

The first monograph on the geology and mineral resources of the Philippines written by a mining engineer was published one hundred thirty-nine years ago. Though noteworthy as a pioneering effort, this work contained only a brief description of the country's resources. Thirty-six years later, a more exten-

sive memoir was published by Centeno y Garcia. This memoir covers the physiography, volcanoes, hot springs and the geology of selected localities, such as Lepanto in Mankayan; Pangasinan; Pampanga; the coal-fields of Cebu; and the Bicol peninsula. Centeno y Garcia also reports on his observations and studies of particular mineral resources: copper, gold, iron, coal, mercury, lead, antimony and sulfur.

Papers dwelling on specific metals were written by other scholars during the last century. Jose del Barco in 1850 reported on iron deposits in Bulacan; Jagor, in 1862, wrote on copper in the Philippines. Marquez de Caicedo published in 1880 a monograph on gold deposits in the Philippines. The American colonists merely carried on the intense work thus devoted by earlier scholars to Philippine geology and physiography, work which, including a memorandum published in 1898, antedated the 1899 paper on the geology of the Philippines mentioned in the dissertation of Hsu.

Besides the work of Centeno y Garcia, other interesting publications on Philippine geology appeared more than one hundred years ago, such as the account of the travels of Feodor Jagor which was published in 1873. Five years later, Dr. Richard von Drasche published his description of the geology of Luzon, which discusses the area surrounding Manila Bay, Pampanga, Arayat, Zambales, the Central Cordillera, Benguet, Bontoc, Laguna de Bay, Taal, Tayabas, Camarines Norte, Camarines Sur and Albay. Analysis of a tuff (a volcanic rock) in San Mateo, Laguna (now Rizal) is given by von Drasche:

Silica	51.69	weight %
Alumina	20.11	weight
Iron oxide	9.36	"
Lime	6.26	"
Magnesia	4.85	"
Potash	1.21	"
Soda	1.97	"
Loss on Ignition	7.07	"

Also present in this work are six photographs, taken through a microscope, of rocks found in the Philippines. In several localities such as Abra and Paracale, von Drasche observes metamorphic rocks such as gneisses and talc schist. These are products

of the reconstitution of the texture and mineral composition of pre-existing rock due to the action of temperature and pressure. The association of gold with metamorphic rocks in Northern Luzon, Camarines Norte and Mindanao is also noted by von Drasche.

Further contributions to the study of Philippine rocks were made by K. Oebbeke in 1881. Five years later, A. R. Bernard published a paper on the rocks of Cebu. At about the same time that the Centeno y Garcia and von Drasche works appeared, August Frenzel wrote from 1877 to 1879 on minerals of the Philippines.

Several works on fossils, which are traces of organisms in rocks, were also published in the 19th century. An investigation of foraminifera, a group of one-celled marine organisms, was undertaken by Felix Karrer, whose study indicated that some of the rocks in Luzon were formed in the early part of the Eocene epoch, a span of geologic time currently placed at 49- to 53-1/2 million years ago.

In the decade preceding Karrer's study on Philippine foraminifera, the famous geologist Beron Ferdinand von Richtofen wrote in 1862 on nummulite-bearing rocks in the Philippines. Nummulites are also foraminifera. Abella y Casariego in 1886 reported the occurrence of nummulites in Cebu. In 1861 and 1863, Fr. Llanos, who described Mt. Arayat, reported on marine fossils in Central Luzon, noting the many species contained in the fossil localities in Tarlac and Camiling. Shells identified by the friar-naturalist include *Berenices, Trochus, Oculina, Astrea, Gryphea, Balanus, Physa, Cerythium* and *Cytherina.*

Around the end of the 19th century (1888 to 1901), Karl Martin, the eminent scientist who worked extensively in Indonesia, contributed to the study of Philippine fossils. In 1896 he wrote:

> "To the age determinations of Philippine fossils it is proper to add that their state of preservation resembles that of the Javanese fossils to a very remarkable extent—to such a degree, indeed, that the specimens from the two regions might easily be confounded. The same statement is true of the tuffs and marls in which they were embedded, and this accords with the fact that the younger massive rocks of the Philippines show an

extraordinary likeness to those of the East Indian Archipelago."

In a report in 1890, Edmund Naumann describes a pygmy elephant fossil from Mindanao which of course he named *Stegodon mindanensis.* Later studies show that this elephant, now extinct, was contemporary with prehistoric man in the Philippines.

The first efforts at oil exploration appeared toward the end of the 19th century. In 1890 Abella y Casariego described rocks in Panay which yielded small amounts of petroleum. In 1896, the first recorded oil drilling in the Philippines was conducted on the estate of Smith, Bell and Company near Toledo, Cebu, where two wells were drilled. One well recovered sizeable quantities of oil after reaching a depth of 244 meters. A small amount of oil was produced from the other well which was drilled to 342 meters. The Philippine Revolution interrupted development of these oil wells. Since then, oil exploration in the Philippines had been unsuccessful, until the discovery in 1976 of the Nido field in the offshore area of Northwest Palawan, from which oil is now being produced in good quantity. Two other oil fields were discovered close to the Nido in 1977 and 1978. The data-gathering and exploration supported by government policies since 1972 have begun to bring benefits to the nation.

During the last century of Spanish rule in the Philippines, the data base which supports our present knowledge of Philippine geology was gradually developed. Mineral resources were identified and an interest in oil exploration started to grow. Earthquakes and volcanic activity were recorded. A number of scientists studied the rocks, minerals, fossils and thermal waters of the Philippines. Understanding of geologic processes expanded and deepened, but it was not until the 20th century that many problems in the earth sciences began to be solved and earth phenomena were interrelated by a unified theory. To the progress in the earth sciences in this century have contributed improvements in techniques of scientific observation, as have experiments on how rocks and minerals are formed, advances in the application of physics to the earth sciences, and technical developments in fields of science related to geology.

An unreeling of the picture that all these comprise is gratifying. At the turn of the century, radioactivity is discovered. Outside the laboratory this process takes place even more intensely in nature, in minerals containing unstable atoms, so that these break down spontaneously. The splitting of the atom, known as fission, produces new substances and results in radiation, including the emission of x-rays. Soon after the discovery of radioactivity, Baron Evarist Rutherford suggests, in 1905, that the amount of products of radioactivity may be used to determine the age of minerals and rocks. From 1908 to 1910, Baron John Rayleigh develops a method of measuring such age, following Rutherford's suggestion. Helium, a product of the breakdown of uranium and thorium, is used by Rayleigh. Other techniques are afterwards developed to determine the age of rocks, with potassium-argon (K-Ar) or rubidium-strontium (Rb-Sr) commonly used as medium. With the radioactive method of dating, geologic events could now be assigned precise time values. Before this, only relative ages of rocks could be stated, using Steno's laws and techniques of correlation.

The application of physics to the earth sciences also allows a better understanding of the structure of the earth's interior. Analyses of earthquake waves and gravity demonstrate the layered character of the earth, as shown in a diagram among the plates. In the center of the earth is a core consisting mainly of iron and nickel. The outer shell of the iron-nickel core is molten and is considered the source of the earth's magnetic field. The presence of this magnetic field is a feature of our planet which has permitted higher life forms to develop because it prevents much harmful solar radiation from reaching the earth.

Also surrounding the core is a thick shell predominantly of iron and magnesium silicates and known as the mantle. The mantle consists of two parts, the upper and the lower mantle. Some portions of the upper mantle may contain small amounts of molten silicate occupying interstices in the mass of solid cilicates. This characteristic and the temperatures in the interior keep the mantle from being too rigid, so that it could undergo plastic deformation when subjected to sufficient stresses over a long period. Asphalt could provide an analogy to the behavior of the mantle. It appears solid and may even be brittle when subjected to short-term stresses, such as a hammer blow. How-

ever, asphalt can also flow, though in viscous form. This region of the earth which can be subjected to plastic deformation is also currently known as the *aesthenosphere.*

The uppermost portion of the earth is the crust. Its thickness varies from about four kilometers under the oceans to as much as 60 kilometers under continents. There is a considerable amount of evidence to show that the composition of the crust under continental areas is different from oceanic crust. The crust is colder than the underlying mantle and hence is more rigid. The crust, together with the upper portion of the mantle which is cold enough to remain rigid, is currently known as the *lithosphere.*

During the decade of the 1960's a revolution in geological thinking took place. A vast body of phenomena, such as distributions of earthquakes, magnetic patterns on the seafloor, morphology or the shape and form of the seafloor, heat flow in oceanic ridges, and many others, could be interrelated and explained by what is now called *plate tectonics.* Under this theory, the earth's surface, specifically the lithosphere, consists of several portions known as plates. Plates may and do separate, and the separation, when it happens, takes place along oceanic ridges. In these places, new plate material is formed from the mantle. There are also places where plates may converge and these are marked by trenches and earthquake activity. While the earth is pictured as dynamic, its seafloor moves at an exceedingly slow pace of one to 10 centimeters a year.

Plate tectonics can therefore explain the concept of continental drift proposed by Alfred Lothar Wegener in 1911. Wegener and others inferred from varied evidence that in the past Africa, South America, Australia and India were joined together in a supercontinent called Gondwana. This supercontinent broke up and its parts gradually drifted apart until, as continents themselves, these reached their present positions. India collided with Asia and the convergence of the two continents produced the Himalayas. Before the development of plate tectonics, there were difficulties in explaining the mechanism of continental drift. Now it is easy to see that the continents are but a part of the lithospheric plates which move away from oceanic ridges. A continent is rafted along, as it were, until it converges with another plate.

The Philippines is a fertile ground for research on plate tectonics since, as already pointed out, it is close to the boundary of the Asian, Australian and Philippine Sea plates. We will see that the Philippines has undergone a complex history through geologic time.

Today, many Filipino scientists are capable of undertaking serious studies on Philippine geology. During the period of American colonialism and after, vast amounts of geologic data were gathered by Filipino and foreign earth scientists. Before 1945, most publications on the subject appeared in the Philippine Journal of Science or in government publications. In 1945, the Geological Society of the Philippines was organized; the quarterly journal of this society has since been a major outlet for papers on Philippine geology. Numerous contributions to Philippine geology are also published by the Bureau of Mines and Geosciences. In 1963, this bureau printed a 1:1,000,000 Geologic Map of the Philippines. An updated version is in preparation and the accompanying text could provide interested readers of this book technical details not dealt with here.

In 1964, the first volume of the serial "Geology and Paleontology of Southeast Asia" was printed by the University of Tokyo Press. Papers on Philippine geology appear in this serial.

Manpower training for the earth sciences is undertaken by several schools, with the University of the Philippines Department of Geology and Geography leading in advanced studies. Data on exploration for oil, gas, coal, uranium and geothermal energy are systematically compiled in the Bureau of Energy Development of the Ministry of Energy.

This part in the Tadhana series on Philippine history benefited from the assistance of earth scientists in the University of the Philippines, the Philippine Bureau of Mines and Geosciences under the Ministry of Natural Resources, and the Bureau of Energy Development under the Ministry of Energy. These scientists have read Philippine prehistory in the record of rocks and fossils. In this rock-and-fossil history many pages are missing or are not yet discovered. This layman's account will try to trace how the Philippines came into being and how the stage was set for the coming of man to the Philippines.

To provide a frame of reference for the subsequent chapters and to offer some degree of orientation to those not too familiar with Philippine geography, an overview of the geography and physiography of the Philippines will be presented along with the present geologic features of the Philippines. With this framework established, a travel through time across well-defined episodes of Philippine geologic history will be made.

The earliest period will cover events up to 135 million years ago. The oldest rocks and fossils of the Philippines dated by modern methods are found in this period. There are indications that the oldest rocks were formed in an environment different from the archipelagic nature of the country; the environment may even be continental. The next period extends up to about 25 million years ago. In this time, the early archipelagic beginnings may be recognized although the distribution of land and sea is different from today's configuration. This is followed by a period extending up to about two million years ago. Rocks in the early part of this time span are the reservoirs for oil in Palawan. Numerous copper and gold deposits as well as coal were formed in this period of geologic time.

This first part of Tadhana's prehistory closes with a description of the environment and setting during the Pleistocene epoch which started about two million years ago. This is a period of fluctuating sea level as a result of the advance and retreat of glaciers. During periods of low sea level, ridges extending from the Philippines to neighboring lands act as bridges on which plants, animals and man move or are transported to and from the Philippine archipelago. Rocks of this period contain evidence that man already inhabited the Philippines then.

That man, prehistoric man in the Philippines, will be the subject matter of the second part of this volume.

Chapter One

GEOLOGY AND PHYSIOGRAPHY: THE PHILIPPINE PROFILE

Nature's craftsmanship has created for the home of the Filipino people characteristics of substance and appearance that together give it its identity. A tropical archipelago, the Philippines lies on the paths of five air streams, which accounts for its frequent typhoons and its dry humid months but nevertheless allows it an equable climate. An analytical tour of the land and the surrounding seas reveals a picture of diversity, magnificence and surprises—a profusion of classes of flora and fauna in their peculiar sanctuaries, from beaches on a shoreline longer than that of the United States, to troughs, ridges and reefs in amazing patterns under the sea, to features generated inland across the ages. In the country's topographic profile are three major islands, 14 imposing mountain ranges with a number of cool green peaks, nine principal valleys and plains, 12 main rivers, a number of fabled volcanoes, and Southeast Asia's largest inland lake. These

formations on land and sea follow three predominant trends, or are formed in three principal directions. A series of erosions, deformations and new generations of land and sea features produced other peculiar elements sculpted upon the rocks and basins of the archipelago to complete the Philippine profile.

IN the western rim of the Pacific Ocean, between the largest body of water in our planet, and Asia, the largest continental mass on Earth, is a cluster of 7,107 islands arranged as if by a deft hand like an inverted, half-open fan. This has been the home of Filipinos since Pleistocene time, more than 750,000 years ago.

These tropical islands, adorned by palm-fringed sandy shores, coral reefs and mangrove forests, have an aggregate area of 30 million hectares. The islands, whose territorial limits extend from 4°30' to 21°25' N and 116° to 127° E, are bounded on the west by the South China Sea which separates the Philippines from the southeast part of the Asian mainland. The portion of the Pacific adjacent to the eastern coast is known as the Philippine Sea. Taiwan, in the north, is separated from the Philippines by the narrow and deep Besshi channel. The Celebes Sea forms the southern border of the fan-shaped archipelago. Near the Celebes Sea, between the islands of Palawan and the Sulu chain, is an internal sea, the Sulu Sea. Just east of the island of Mindanao, the sea bottom plunges to depths averaging 10,500 meters below sea level. This trench, extending from 4° to 15° N and known as the Philippine Deep, has its deepest point at 11,800 meters below sea level, one of the deepest in the world.

The majority (7062) of the islands are small, having areas less than 100 square kilometers; these comprise only two per cent of the land area of the Philippines. Their irregular coastline has a combined length estimated at 17,500 kilometers, about twice as long as that of the United States. Only 11 islands have areas more than 2,500 square kilometers, and eight of these are found in the middle portion of the country, the Visayas. The two largest islands, Luzon in the north with 105,708 square kilometers and Mindanao in the south with 95,600 square kilometers, constitute 67.1 per cent or more than two-thirds of the land area of the archipelago. The other major islands, in their order of decreasing size, are Samar, Negros, Palawan, Panay, Mindoro, Leyte, Cebu and Bohol.

A warm, tropical climate with a mean annual temperature of 27° C prevails in the lowland areas of the islands. From north to south, there are no significant temperature variations in these areas. In Laoag, in the northwestern tip of Luzon, the average temperature of the area's coldest month, January, at 24.8° C is only 3.8° C lower than the average temperature of May, the warmest month. Jolo, in the south, has an average temperature in February, the coldest month, of 26.0° C, only slightly below the average of 27.9° C for August, the warmest month there. At the higher elevations of the highlands, lower temperatures prevail. Baguio City, at an elevation of 1,154 meters, has a mean temperature of 16.9° C in January and 19.9° C in May. Occasionally, temperature drops to 10° C during the coldest months. At still higher elevations, as in the Mountain Trail in Bontoc, wind and low temperatures combine to form frost at elevations above 2,250 meters during cold nights in January and February.

Inasmuch as the Philippines is surrounded by large bodies of water, its relative humidity is high, from an average of 71 per cent in March to 85 per cent in September. Abundant rainfall in most areas keeps the greenery lush and the soil fertile. There are, however, significant variations in the rainfall patterns, as shown in the climate map shown among the plates. The lowest total annual rainfall recorded is 875 millimeters, in Aggunetan (Gattaran) in Cagayan. The highest annual rainfall, 5375 millimeters, was recorded in Baras, Catanduanes. Of 459 stations, 162 measured an average total of at least 250 mm.

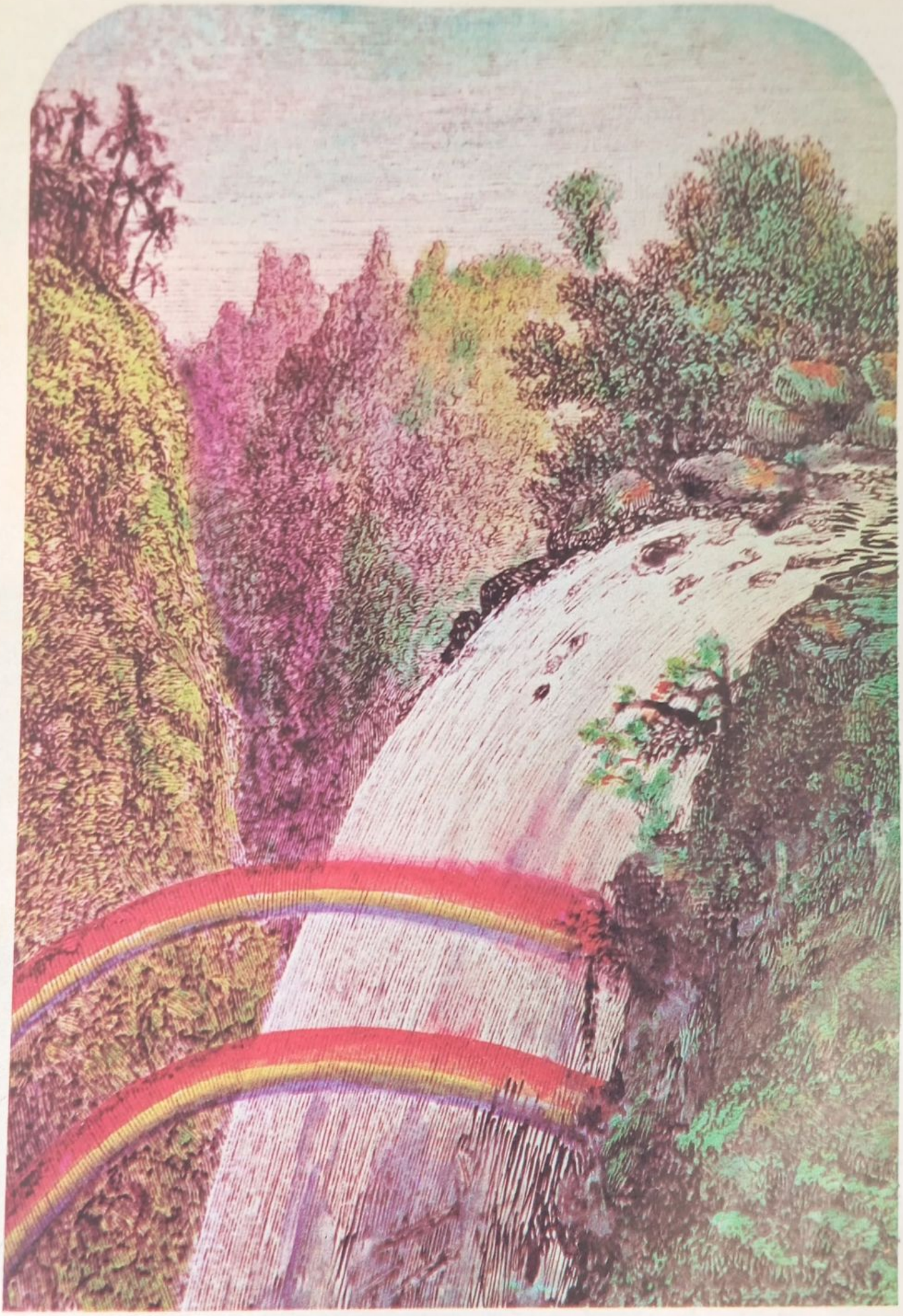
It may be noted from the rainfall map that the western areas of the country have a pronounced dry and rainy season, with 90 per cent of the annual rainfall occurring during a five- to six-month season. The eastern parts, on the other hand, do not have a dry season. In the central portions, there are months, generally November to April, when the monthly rainfall is less than 60 millimeters.

The seasonal pattern of climate in the Philippines is affected by five air streams—the Southwest Monsoon, the Northeast Monsoon, the North Pacific Trades, the Middle Latitude Westerlies, and the South Pacific Trades. The first two, the most important air flows, have been bestowed Filipino names: *amihan* for the Northeast wind, and *habagat* for the Southwest wind. Both air streams arise from the heating of the Asian continent

during spring and summer and its cooling during winter. Heating of the air over Asia creates a strong and deep low-pressure area which sucks the colder air from the southern hemisphere. The resulting northward flow of air is deflected in a northeasterly direction owing to the rotation of the earth. In the vicinity of the Philippines, this air flow, the Southwest Monsoon, originates from the Indian Ocean. It is a warm humid air that usually reaches the Philippines in early May, building up here to a peak force in August and diminishing in October. In that interval, the western parts of the Philippines undergo the rainy season.

The pattern of flow is reversed during winter when the Asian continent cools, thus forming a high-pressure area known as the Siberian High. The Northeast Monsoon is a continental polar air mass with low moisture content and a temperature of about -20° C when it leaves Northeast Siberia. The air mass picks up moisture during its passage over the Pacific. This moisture is dropped as the air is forced up by the eastern coastal mountain ranges of Luzon and Mindanao, hence the heavy rainfall in the eastern parts of the Philippines. December to May is the season of the Northeast Monsoon.

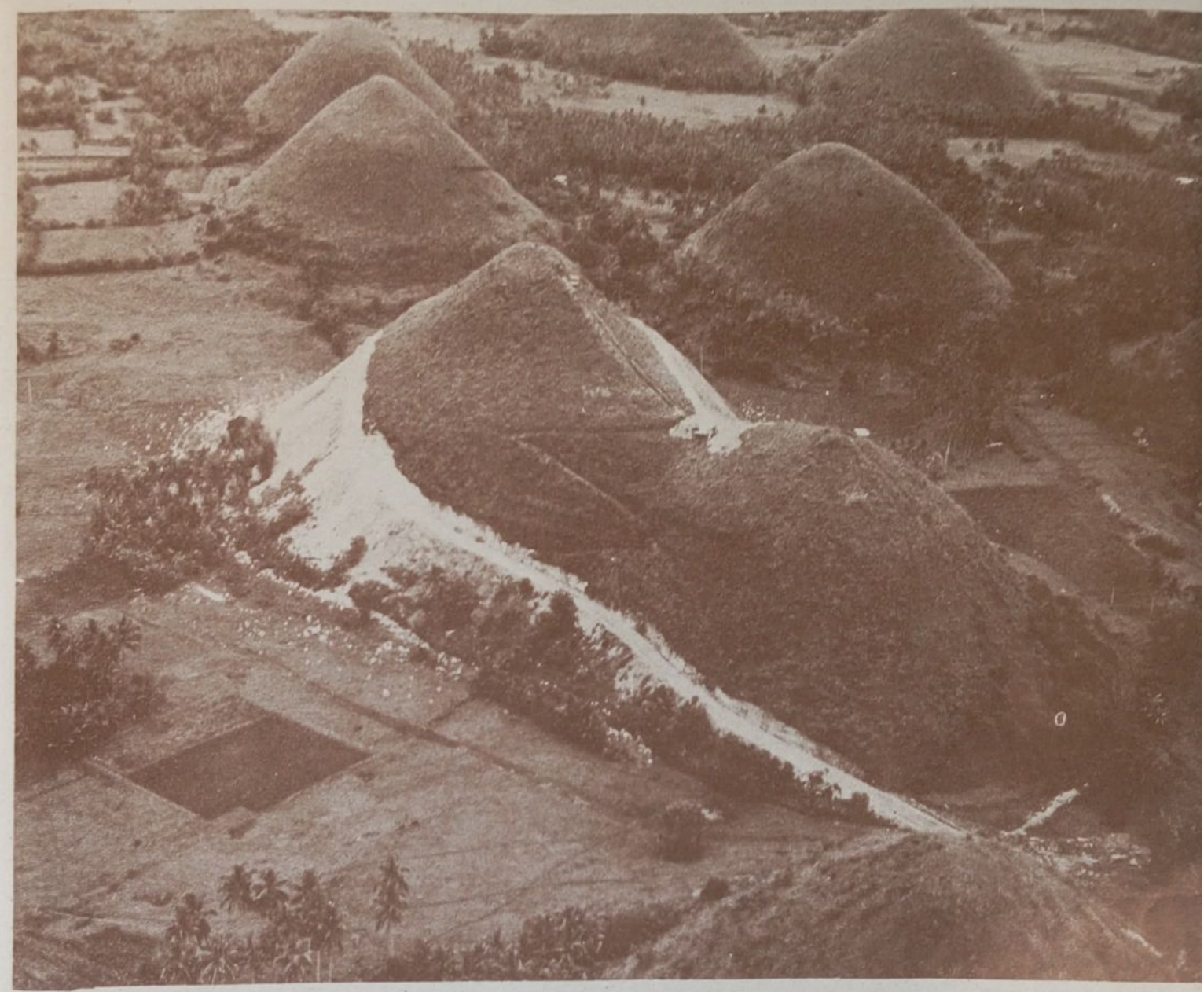
The Philippines is also affected, from May to October, by the meeting of air streams from the northern and southern hemispheres. This area of confluence is known as the Intertropical Convergence Zone; when broken up by monsoonal influences, the convergence produces low-pressure areas that may develop into tropical revolving storms known as typhoons. These typhoons originate mostly in a general area extending from the Caroline and Marshall Islands, the Marianas to Taiwan. The typhoons move in a west-northwest direction toward the Philippines, with the Eastern Visayas, Eastern Luzon and Northern Luzon usually bearing the brunt of the furious rain and the winds that easily exceed a velocity of 100 kilometers per hour. Although typhoons may occur any time during the year, the normal typhoon season usually lasts from June to December, with the greatest frequency in August. The heavy rains and strong winds cause great damage to property, agriculture, public works and industry. Many lives are endangered by accompanying floods. In May, 1976, typhoon Didang brought such heavy rains that, in the Manila area, 450 millimeters of rainfall were recorded over a 24-hour period. More recently, typhoon Dading caused



The Philippines: an Oriental Eden

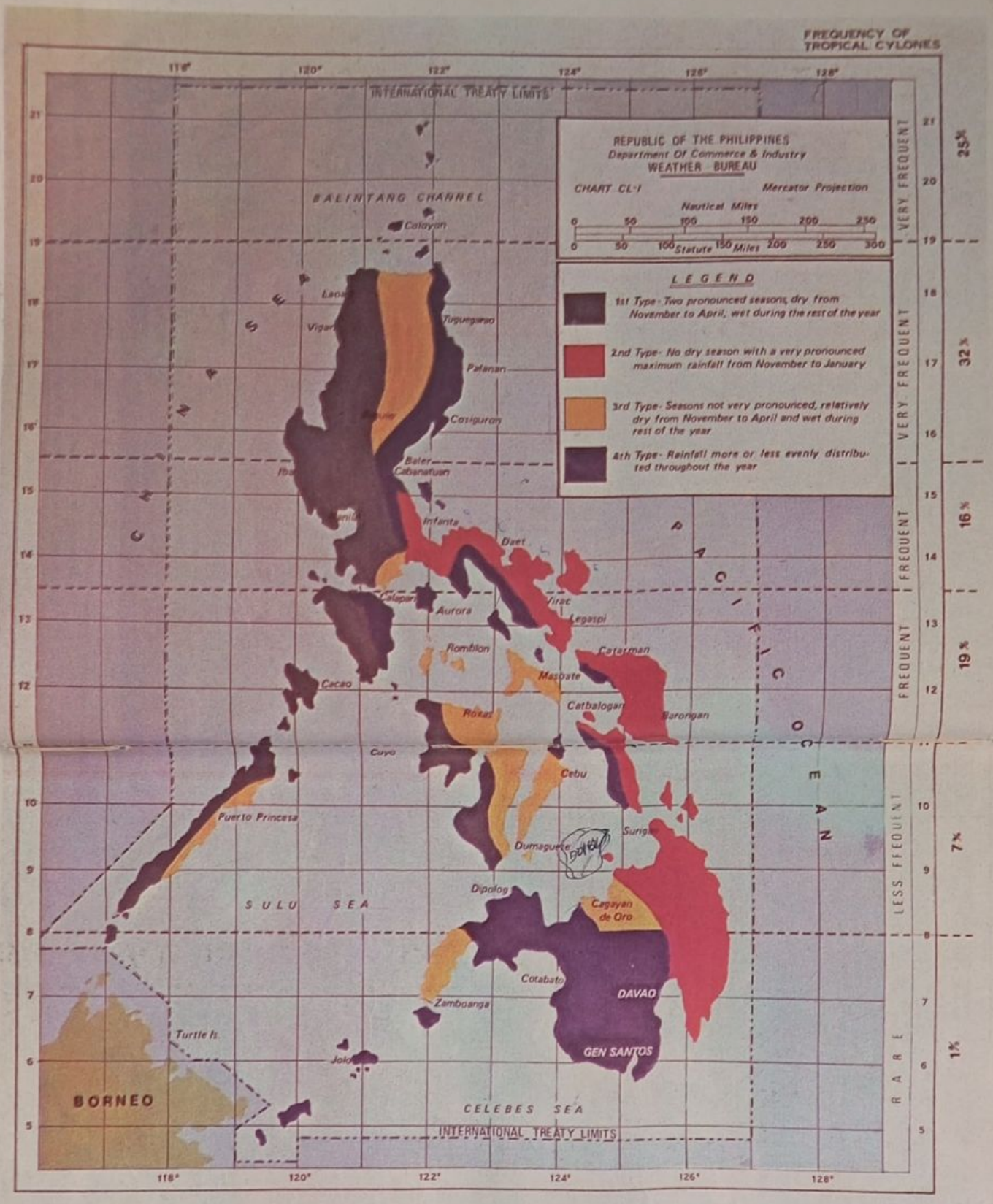
. . . where lofty and rugged mountain ranges sheltering fertile valleys, plateaus, lakes and volcanoes, swamps, beaches and reefs abound.

The perfectly symmetrical Mayon Volcano and the Chocolate Hills of Bohol are some unique features of the Philippine topography.



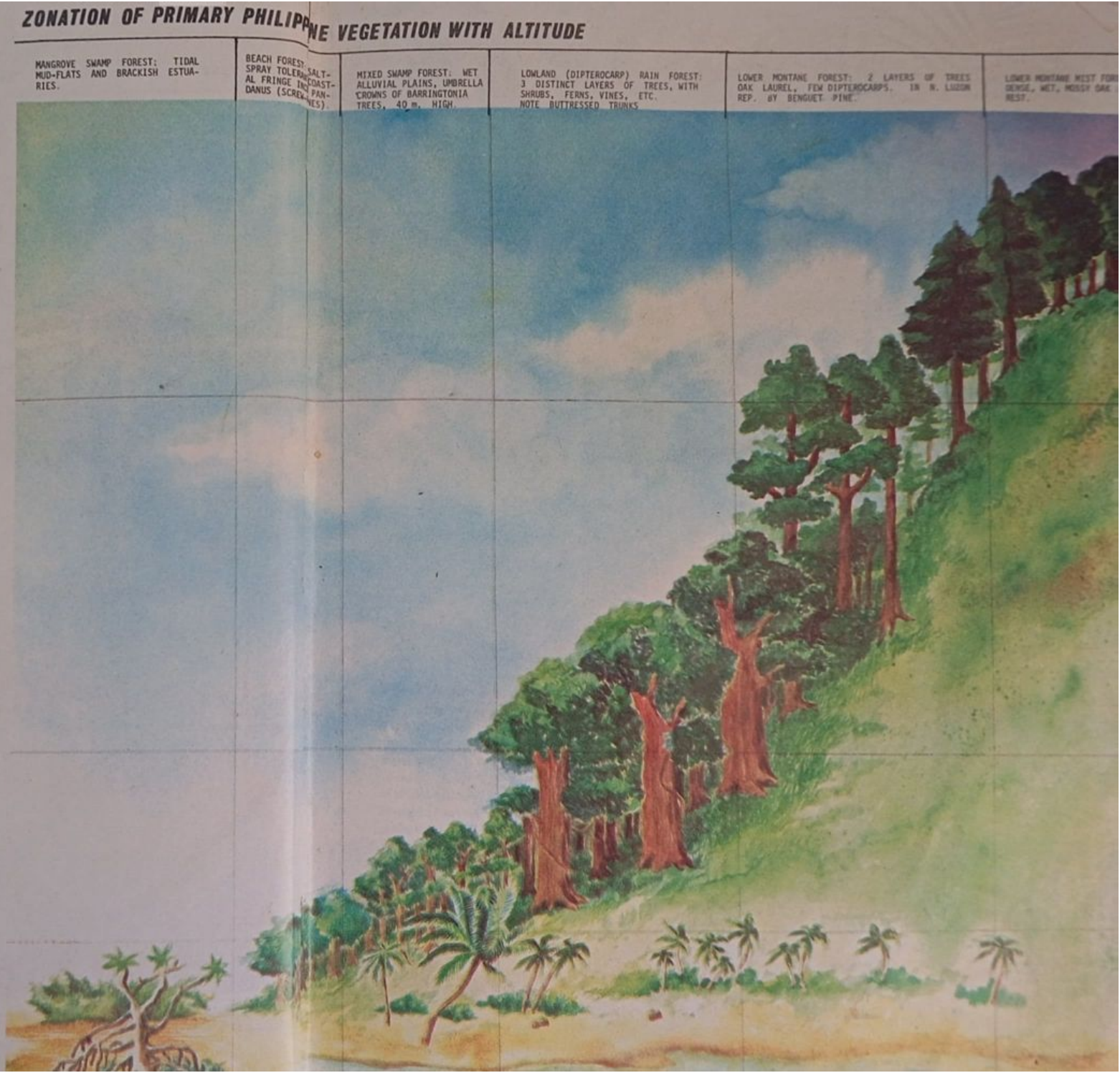
THE MONSOONS OF TROPICAL ASIA

The Monsoons of Tropical Asia — January (left) and July (above). Alternating patterns of weather system result from the cooling of Asia during winter and its warming in summer.

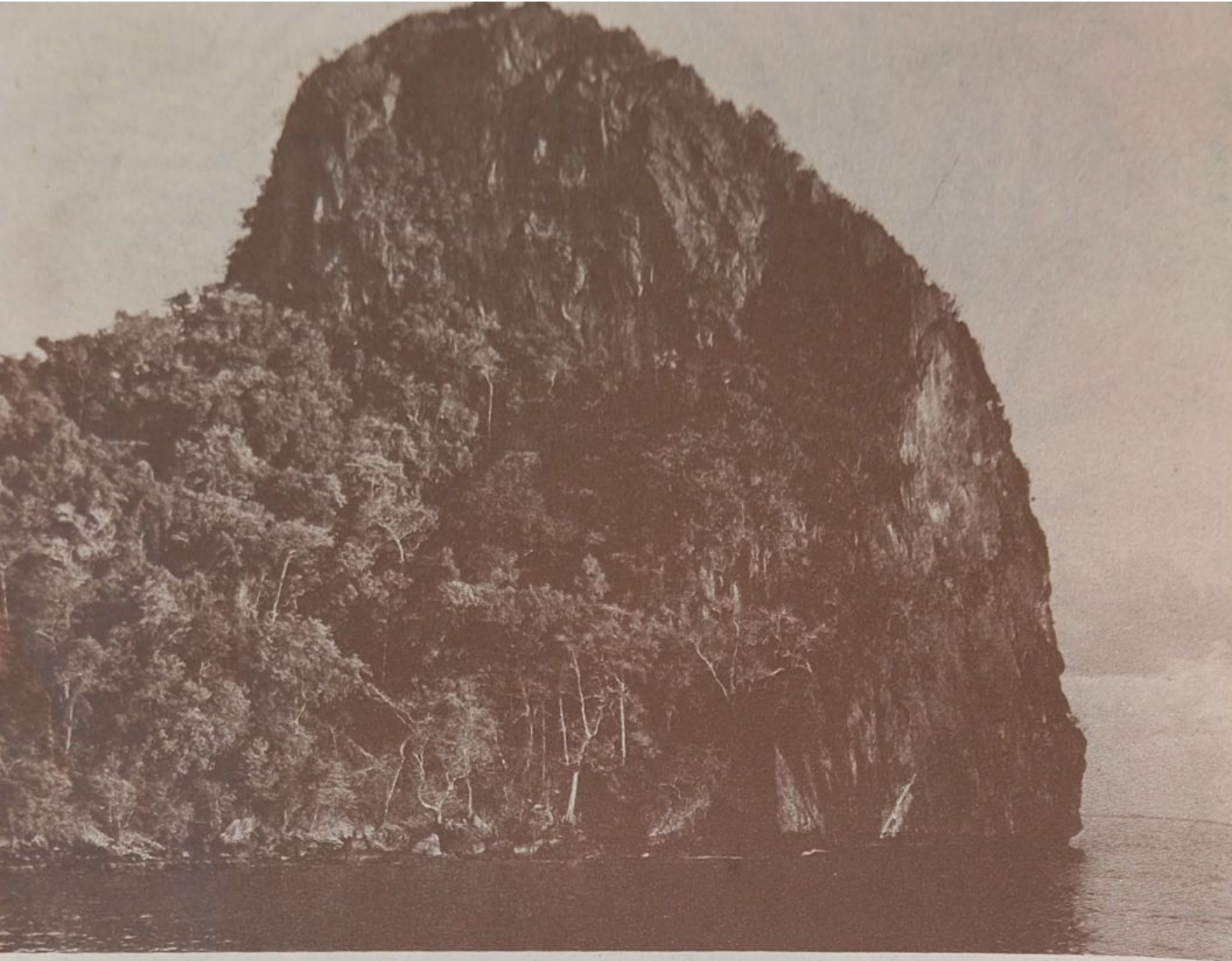


Climate Map of the Philippines

Variation of Philippine Vegetation with Altitude.


ZONATION OF PRIMARY PHILIPPINE VEGETATION WITH ALTITUDE
MANGROVE SWAMP FOREST: TIDAL MUD-FLATS AND BRACKISH ESTUARIES.
BEACH FOREST: SALT-SPRAY TOLERANT COAST-AL FRINGE INCLUDING PAN-DANUS (SCREW PINES).
MIXED SWAMP FOREST: WET ALLUVIAL PLAINS, UMBRELLA CROWNS OF BARRINGTONIA TREES, 40 m. HIGH.
LOWLAND (DIPTEROCARP) RAIN FOREST: 3 DISTINCT LAYERS OF TREES, WITH SHRUBS, FERNS, VINES, ETC. NOTE BUTTRESSED TRUNKS.
LOWER MONTANE FOREST: 2 LAYERS OF TREES OAK LAUREL, FEW DIPTEROCARPS. IN N. LUZON REP. BY BENGUET PINE.
LOWER MONTANE MIST FOR... DENSE, WET, MOSSY OAK ... REST.

Around numerous beaches are characteristic vegetation including the nipa palm (left), the screw pine — Pandanus (opposite page, above left) and the rattan (opposite page, above right.) Pollen of similar plants are found in Philippine rocks formed ***more than 20 million years ago.***



The cliffs of Nido in Palawan (above) illustrate the influence of topography on vegetation. A dipterocarp forest clings tenaciously on a limestone promontory. The two-winged apitong or Dipterocarpus grandiflorus (opposite page, below left) shows the origin of the name of the dipterocarp family.

At higher elevations in Luzon and Mindanao, pine forests (top of the opposite page) replace vegetation of the lowlands. In Norhtern Luzon, Pinus insularis (opposite page, below right) predominates in the upland forests.

A sheltered waterfall (overleaf) forms a niche for the lush vegetation of the archipelago.

Apitong *Dipterocarpus grandiflorus*

flash floods in Central Luzon, claimed many lives and destroyed homes, crops and livestock.

The climate clearly calls attention to the transcendence of environmental preservation over national boundaries. The cool Christmas air may have begun its journey thousands of kilometers away, traveling over several countries and a vast expanse of sea. The summer rain that imparts a freshness to dry and dull nights, irrigates fields, and replenishes watersheds is borne by winds from the Indian Ocean. The atmosphere to which they rise from seas that gird the globe are without doubt the common lifeblood of humanity, and conversely, environmental deterioration that begins at one point could spread ruin across any number of national borders. Fortunately, increasing awareness concerning the problems of the environment, aided by scientific and technological advances, contributes to the maintenance of a healthy environment. In this environment life evolved, and as we shall see in the next chapter, it is the product of several billions of years of growth and change. Man's increasing consciousness that even this edgeless and inconceivably rich creation is not indestructible is probably the only source of hope that it will remain, to sustain life for endless eons.

The warm, equable climate of the archipelago, its abundant rainfall and its rich soil produced an environment which nourished varied and abundant plant and animal life. A later chapter will review evidence that a favorable climate existed even during times when Asia and Europe were covered by thick sheets of ice. The earliest Filipinos therefore enjoyed the bounty of nature in this assemblage of large and small islands, a tropical Eden whose varied topography has provided a home to numerous forms of life. Around many islands, the brutal force of waves is mitigated by magnificent reefs whose premises teem with rainbow-colored fish, shells and corals. The record that may be read in rocks shows that similar reefs existed in the past, and may have been sources of food for early man in the Philippines. Today, oil companies deploy modern instruments among buried reefs in search of the valuable resource formed by the remains of marine life that flourished in the past.

Ribbons of sandy beaches adorn the coast. The shore typically supports vegetation consisting of *Pandanus* (screw pines),

Casuarina equisetifolia (agoho), *Calophyllum inophyllum* (palomaria), *Ficus balete* (balete), *Cycas rumphii* (pitogo), *Terminalia catappa* (talisay), *Sterculia foetida* (calumpang) and a number of grasses, shrubs, vines and hedges. In places, mangrove swamps protect the land from erosion by the sea while also producing food essential in the elaborate scheme of life in the sea. The vegetation dominant in these mangroves are *Rhizophora apiculata* (bakawan), *Bruguiera gymnorrhiize* (busain), *Ceriops tagal* (tangal), *Nipa fruticans* (nipa), *Sonneratia* (pagatpat) and *Avicennia* (apiapi). Today, mangroves are important sources of fuel. Nipa palms provide roofing material and sap which could be fermented into wine, alcohol and vinegar. Pollen grains of the nipa and mangrove are found in ancient rocks in the Philippines in nearby Borneo, encouraging the theory that early man in the Philippines must have utilized the mangroves of his time for food, fuel and shelter.

Life's varied forms

In many places, rising at the edge of the sea are jagged mountains with a mantle of greenery upon which at appointed times clouds sprinkle life-sustaining rain. As one travels inland from the shore and up the highlands, a systematic change in the vegetation will be noted, a change schematically depicted in one of the plates. The variations in environment and sources of flora have given this country a rich endemic plant life, so much so that about 3000 different species of Philippine forest trees have already been catalogued. Numerous flowering plants, among them jasmine, sampaguita, hibiscus, ilang-ilang, fire trees, acacia, frangipani, orchids and lilies, clothe the land in a splendor of scents and color.

These plants provide not only beauty but also food. In the lowlands, at elevations below 300 meters above sea level, coconuts thrive in places of high moisture or rainfall measuring at least 1800 millimeters annually. All parts of this plant can be used by man—as food, roofing material, timber, fiber, fuel and a variety of other necessities. Coconut oil from the seed is used for cooking and for a number of domestic and industrial uses, as for making soap, ointments, cosmetics and candles. Coconut oil has also been found to be an excellent substitute for diesel fuel. The coconut meat is a rich source of protein, and the shell

yields charcoal of high quality. Sap from the flowers is fermented into palm wine known as *tuba,* which when distilled becomes a potent drink known as *lambanog.* Because of its versatility, the coconut is justifiably called the tree of life. It is an important part of the Philippine economy because copra and coconut products rank high among the exports of the Philippines.

On the lowlands and plains are grown important food plants such as rice, sugarcane, corn and vegetables. A wide variety of fruits also grows on the plains and mountains of the Philippines, including the banana, mango, cashew, santol, breadfruit. durian, jackfruit, guava, atis (custard apple), mabolo (fruit of the ebony tree, a variety of persimmon), mangosteen, rambutan, sugar palm and many others. Related to the mango and the cashew is the sineguelas (*Spondias purpuria*).

The bulk of timber known as Philippine mahogany comes from lowland forests dominated by a few species of trees belonging to the tree family known as the *Dipterocarpacea.* The trees of this family bear fruits with two to five wings, hence the name of the family (from the Greek, *di* twice; *pteron,* wing; *karpos,* fruit). Several layers of trees may be recognized in the dipterocarp forest. The uppermost layer consists of trees which have crowns 30 to 40 meters high; in this group the dominant ones are the white lauan *(Pentacme contorta);* red lauan *(Shorea negrosensis),* tangile *(Shorea polysperma);* guijo *(Shorea guiso);* bagtikan *(Parashorea plicata);* yakal *(Hopea acuminata);* apitong *(Dipterocarpus grandiflorus).* Associated with these dipterocarps of the uppermost level are trees that belong to other families, such as the dao *(Dracontomelon dao);* pili *(Canarium ovatum);* duhat *(Syzygium cumini);* and alakaak *(Palaquium gigantofolium).* The middle layer, with trees averaging 18 to 20 meters in height, commonly consist of balobo *(Diplodiscus paniculatus)*; kamagong (*Diospyros philippinensis*); katmon (*Dillenia philippinensis);* anonang *(Cordia dichotoma);* and a number of subsidiary species. The lowest tree layer, with heights of six to 10 meters, include species belonging to the following genera: *Grewia, Garcinia, Laportea,* and *Leea.* Below six meters are shrubs and a ground layer of ferns, herbs and mosses. Hanging from trees are vines, orchids, rattans and climbing figs.

Maximum development of the dipterocarp forests is attained in areas without a short dry season, or with only a short one; such areas are always damp and humid, and are found at elevations below 700 meters. Three-fourths of the timber in the Philippines come from dipterocarp forests. In the past, a small portion of lowland forests was occupied by the molave *(Vitex parviflora)*, associated with the narra *(Pterocarpus indicus)* and tindalo (*Afzelia rhomboidea*).

At higher elevations, usually starting at 1000 meters and rising to 2700 meters or more, trees of the mid-mountain or lower montane forest become dominant. Trees belonging to the laurel family (Lauracceae), which includes *Cinnamomum, Litsea,* and *Neolitsea,* and oaks *(Quercus* spp.,), are well represented in this type of forest. Tree ferns and ground herbs replace the palms and vines of the lowland forests. In Mindanao, southern conifers such as *Podocarpus, Phyllocladus* and *Agathis* bear affinities with Australian flora. On the other hand, pine forests of Luzon and Mindoro suggest land connections with the Asian mainland. *Pinus insularis* is the most common species in the pine forests of the mountains of Benguet, Mountain Province, Kalinga-Apayao and Ifugao, while *Pinus merkusii* is found in some areas in Zambales and Mindoro which have been restricted to preserve the species. The lower montane forests are typically open and sunny.

At still higher elevations, constant, daily mists promote the development of a different type of forest, one known as the lower montane mist forest. This is a dimly lit, dense, mossy forest on which grows only one layer consisting of trees about six to eight meters high. This mossy forest is the domain of species belonging to *Eugenium, Eurya, Quercus, Lithocarpus, Myrica, Neolitsea, Podocarpus* and *Symplocos.* In Mount Pulog, above 2750 meters, the summit area of several square kilometers is occupied by an open grassland dominated by the dwarf bilaw (*Miscanthus*), a species associated with the dwarf bamboo (*Arundinaria*) and the grasses *Calamagrotis, Anthoxanthum, Deschampsia* and the plants *Anaphalis, Euphrasia, Gentiana* and *Ranunculus* which are suggestive of a sub-alpine habitat.

Open plains and hills of the Philippines are covered mainly by kogon *(Imperata cylindrica)* and talahib *(Saccharum spontaneum)*. Talahib, the taller species of the two, is more often

found in sandy and gravelly soils, while the more aggressive cogon is usually found in clayey soil. Open lands that are wet to swampy are favored by the tambo (*Phragmites vulgaria*). In highlands where pine forests are found, punaw (*Themeda triandra*) and bilaw (*Miscanthus sinensis*) take the place of cogon and talahib.

The forests and grasslands are home to a great variety of land animals, some of which are endemic, or unique to the Philippines. Some of these endemic species like the monkey-eating eagle (*Pithecophaga jeferryi*), now known as the Philippine eagle, and the tamaraw (*Anoa mindorensis*) are today threatened with extinction. The tamaraw, smaller than the carabao, with v-shaped horns in its adult years, is found only in the island of Mindoro where bamboo thickets provide it with both shelter and food. The monkey-eating eagle, which stands about three-and-a-half feet, is found in the Sierra Madre mountains of Eastern Luzon and in the heavily forested areas of Mindoro. It feeds mostly on monkeys but it has also been observed to feed on young pigs, wild cats, flying lemurs and flying squirrels.

Another threatened species is the tarsier (*Tarsius philippinensis*), found in Bohol, Leyte, Samar and Mindanao. The tarsier is the smallest of the primates, the mammalian group which includes man. This animal with strikingly large eyes, is a nocturnal animal that lives in trees and feeds on insects. The tarsier is also found in Borneo and Celebes. It is related to the lory of Tawi-Tawi, a species also on the brink of extinction.

The tree shrew (*Tupaia cuyonis*), found in Cuyo Island, is the most primitive of the primates, and is believed similar to the earliest primates that evolved from a more generalized mammalian ancestor. It is also found in Borneo, Java, Sumatra, the Malay peninsula, Burma and India. The other primate found in the Philippines is the monkey (*Macaca philippinensis*), which enjoys a wider distribution.

The mouse deer or chevrotain (*Tragulus nigricans*) is another form of vanishing wildlife. Today, this is found only in Balabac Island, south of Palawan. Other mammals restricted to the province of Palawan are the pangolin or scaly ant eater (*Manis javanica*), badger (*Mydaus marchei*), the binturong or bear cat (*Arctictis*), the otter (*Lutra ciaerca*), spiny ant eater (*Thecurus pu-*

milis) and the mongoose *(Mungos)*. Some squirrels are located only in Palawan, Sulu and Basilan; the weasel is found only in the first two provinces.

The wild pig *(Sus celebensis)*, deer *(Cervus spp.)*, wild cat *(Felis minuta)*, palm civet *(Paradoxurus philippinensis)*, civet *(Viverra tangelunga)* and various rodents show a wide distribution in the islands of the Philippines. A number of species of bats, some feeding on insects, others on fruits are also found in the country.

The grasslands, forests, swamps and the sea shelter a number of reptiles, the class in which crocodiles, turtles, lizards and snakes belong. Two species of crocodiles are found in the Philippines, the salt water crocodiles *(Crocodylus porosus)* and the Mindoro crocodile *(Crocodylus mindorensis)*. The smaller Mindoro crocodile, reaching a maximum length of 2.4 meters, is restricted to the inland waters of Luzon, Mindoro, Mindanao and Sulu. The salt water crocodile, reaching a length of 6.1 meters, has a wider range of distribution. Four species of land turtles are found in the Philippines. The marine hawksbill (*Eretmochelys imbricata*) is the source of tortoise shell.

Lizards and snakes comprise the majority of reptilian species. The reticulated python (*Python reticulatus*), found in the Philippines, grows to a length of about 10 meters and is the largest snake in the world. On the other hand, the brahminy blind snake *(Typhlops brahminus)*, which grows to only about 15 centimeters, is one of the smallest snakes in the world. Also found in the Philippines is the largest venomous snake in the world, the king cobra *(Ophiophagus hannah)* which grows to a length of about 5.5 meters. Although there are more than 70 species of land snakes listed in the Philippines, only seven are venomous and these belong to two families—Elapidae (cobras and coral snakes) and Crotalidae (pit vipers). Sea snakes (hydrophiidae) and sea kraits (Laticaudidae) inhabit the marine waters of the Philippines. One species of the Hydrophiidae, however, the *Hydrophis semperi*, is found in Lake Taal. Sea snake venom is extremely toxic, some species having venom more toxic than that of the most venomous land snake.

House lizards in the Philippines, *Hemidactylus frenatus*, *Gehyra mutilata* and *Cosymbotus platyrus*, belong to the family

Gekkonidae which also includes the *tuko* or *(Gekko gecko)* and the *Gekko monarchus.* The largest Philippine lizards are the monitor lizard (*Varanus salvator*) and the sailfin water lizard (*Hydrosaurus pustulosus)* which grow to two meters and one meter, respectively. Lizards belonging to the genus *Draco* have flaps of skin which permit them to glide from tree to tree, hence the term "flying lizard." These flying lizards, *Calotes spp.* and *Gonyocephalus spp.*, like the chameleon, have the ability to change color to blend with their surroundings.

Frogs and toads belong to the class amphibia, two orders of which (Anura and Apoda) have Philippine representatives. Angel C. Alcala in 1976 notes that tailed amphibians (Urodela), which include the salamander, have not been found in the Philippines.

Contributing to the music of the forests are 450 species of resident birds about 150 species of migrant birds. Next to fishes, birds have the greatest number of species among vertebrates of the Philippines. Among Philippine birds are doves, pigeons, kingfishers, egrets, mallards, thrushes, hawks, crows, owls, swifts, cuckoos, woodpeckers, starlings, parrots, swallows, cranes, herons, hornbills, rails, snipes, grills and sandpipers. The tabon or megapode (*Megapodius freycinet*) is a representative of the primitive bird known as mound builder or brush turkey, which is also found in Borneo. In Palawan, nests of the swiftlet (*Colocalia inexpectata*) are gathered and highly prized in the making of a popular kind of soup. These nests are made of the hardened saliva of the swiflet.

Many birds are endemic. Roy E. Dickerson in 1928 suggests that the distribution of the hornbills (*Hydrocorax*), which developed into different species, is related to ancient configurations of land in the Philippines.

Fishes, which constitute the vertebrate group with the greatest number of varieties, come in all sizes, from the tiny *Pygmae pandaka* to the giant whale shark (*Rhinocodon typus*), which grows to more than 15 meters. Among the common freshwater fishes caught for food are the dalag or mudfish (*Ophiocephalus striatus*), several varieties of catfish, with the hito (*Clarias batrachus*) being the most common. Members of the carp family are found in Mindoro, Palawan, and in provinces of Mindanao, especially Sulu,

where a variety of gourami is also present. There are many brackish water species, as well as species that spend part of their life cycle in the sea. The *bangus* or milkfish (*Chanos chanos*) is an example of the latter. Gobies, eels and mullets can live in the sea as well as in streams and lakes. Young gobies are caught in large numbers, salted and fermented into *bagoong*, a condiment also found in such other Asian countries as Indonesia, Thailand, Vietnam and Korea. The liquor of *bagoong* is also extracted and is the source of the flavoring known as *patis*, another nearly indispensable household item in Southeast Asia.

Philippine seas abound with anchovies, sardines, mackerel, tuna, pompano, sea basses, shark stringrays, snappers and flying fishes. The great white shark of recent movie fame (*Carcharodon carcharias*), hammerhead and tiger sharks prey in Philippine waters. Seafaring mammals such as the porpoise, dolphin, whale and manatee (*Dugong dugong*) also enjoy the warmth of the tropics around the Philippines.

Before examining further other fauna of the sea, let us return to the land and look at lower animal forms that lurk in Philippine forests, streams and plains. A large number of joint-legged organisms known as arthropods, which include insects, spiders and crustaceans, also find in the archipelago a tropical habitat. Mosquitoes, flies and cockroaches are among the pests that irritate man but they also provide food for birds, bats and other animals. Some insects, like the large ant and some varieties of beetles, comprise gourmet food in some areas of the Philippines. Insects also perform the important role of fertilizing plants by carrying pollen from their flowers.

In addition to their practical uses, insects complement the numerous colors of Philippine birds and flowers. Butterflies and moths are adorned by a great variety of patterns and colors that make them favorite material for zoological collections. The largest among Philippine butterflies is the rare species *Papilio trojana*, found in Palawan, which attains a wing span of 18 centimeters. Among the smallest in the archipelago, found in various parts of Luzon and the Eastern Visayas, is the *Lamproptera megesdecius*, with a wing span of only about four centimeters. Estimates on the number of varieties of butterflies and moths range from 800 to 3,800. A number of dragonfly varieties are also known in the Philippines.

In lakes, streams and in the sea, arthropods also thrive, so that Filipinos for centuries have gathered shrimps, crayfishes and crabs for food. Shrimp fry are also salted and fermented into a variety of *bagoong*.

In Philippine forests and even in farms and streams leeches may be found. Also harmful to man are a number of parasitic worms that infest animals and man. These and other lower forms of life, however, are still part of the web of life. Earthworms, for example, help the soil remain fertile. In harsh environments, especially where pollution has set in, worms and various burrowing organisms are among the first life forms to settle and restore equilibrium to a habitat upset by the wastes and poisons of modernization.

Molluscs, the animal group which includes snails, clams, octopi and squid, are another lower animal form well represented in the archipelagic environment of the Philippines. Land snails, fresh water snails, mussel and clams inhabit the islands. The shores, swamps, reefs and seas hold molluscs of so many kinds as to make the Philippines—and the Indo-Pacific region—the richest in terms of variety. Both the fresh-water and salt-water types provide food. Other products yielded by molluscs include pearl from oysters and mother-of-pearl from the species *Placuna placenta* which can be converted into buttons, window panes and a variety of handicraft items.

Some of the shells highly prized by collectors for their form, color or rarity as a species are encountered in Philippine seas. Among these are the glory of the sea cone (*Conus gloriamaris*), golden cowry (*Cypraea aurantium*), wentletraps (*Epitonium scalare* and *E. pallasi*), carrier shells (*Xenophora solaroides* and other species of the family *xenophoridae*), the intricately sculptured shells of the murex family (e.g. *Pterynotus elongatus*) and thorny oyster (*Spondylus regius*).

The variety of corals, sponges and the color of underwater gardens in the reefs of the Philippines make the islands a paradise for skindivers and marine scientists. Associated with the corals are algae (sea weed), lower plants important as sources of food for man and other organisms. These are also valuable because they produce oxygen from the carbon dioxide expelled by animals. Different kinds of coral-algal reefs are found in the Philippines.

A barrier reef is found in Bohol; the Apo reef off Mindoro is a double atoll; table reefs are found along the Sulu chain of islands, while fringing reefs hug the shores of many small and large islands. As mentioned earlier, ancient reefs have become important reservoirs of oil and gas, hydrocarbons generated from the remains of marine life that thrived in Philippine waters millions of years ago.

Life-giving environment

The wide variety of life now found in the Philippines is the result of a favorable environment. A similar environment in the distant past may be deduced from the record of the rocks. These organisms did not settle on the land and seas of Philippines only during historic times. The splendor of tropical life, and the wealth of the forests, lakes, streams and seas were already evident when early man lived in the Philippines. He saw a land that pleased his senses, and in his bones stirred the knowledge that earth and sky, the life-giving essence around him had been generous. Various forms of life, creatures that moved or grew, flourished because suitable terrains and soils gave shelter to organisms with requirements for survival obviously different from each other. Let us now look at the topography and the underlying rocks which form the Filipino's ancient homeland.

It can bear repeating that in many of the large islands of the Philippines there exists a variety of landforms developed on a complex subsurface architecture; the picture they conjure is not the simple one of a palm-covered tropical coral island. On these varied contours sculpted by nature's relentless processes of accretion and erosion, diverse plant and animal communities flourished. These communities combined with the varied landscape to compose a complex and fascinating picture.

The landforms also influenced the subsequent evolution of Philippine culture and history. Seaways between fragmented islands, mountain ranges and forests formed natural barriers that made inevitable the development of heterogeneous languages and modes of life among the pristine communities of the archipelago. During the intrusion of European and American colonizers, a geopolitical awareness, a perception above the level of communal instinct, influenced the selection of strategic sites and political centers. Manila, for example, has a combination of phy-

sical features that favored its growth as the prime city of all the islands. Its uniquely shaped and situated bay, protected by the island of Corregidor, the Zambales Range and the peninsula of Cavite, is an ideal site for a port. The hinterland to the east, the Sierra Madre range, is a formidable natural wall against invaders from the Pacific. The Central Plain of Luzon is large and near enough to supply food and other necessities to the community in Manila and thus support its fast growth. Luzon, itself, has varied resources to encourage the development of foreign trade. The other main islands were not found by seafaring ancestors to possess the same combination of features that encouraged the growth of Manila.

The strategic location of the Philippines was realized by Americans, as it had been by the Spanish colonists whom they replaced at the turn of the century. Apart from serving as an excellent stepping stone to the Far East, the archipelago had another geographic value explicitly stated by Warren Dupre Smith in 1925:

> "Another fact of geographic importance to the Americans at least and which is of first importance in the political question of the future of the Philippines, is that the Philippine archipelago lies directly athwart the entrance to the great all-water World-way leading from the Pacific Ocean to the Atlantic by way of the Indian Ocean and the Mediterranean. For this reason alone Americans particularly and all geologists should be interested in the geology of that region. The Philippine islands occupy a position comparable in the East Indian region to that of the Antilles in the Caribbean."

Recent events in Southeast Asia and the Middle East show that geography and geology are as important in the present age of jet planes, missiles and nuclear ships as they were in the past when the sea alone determined prime strategic planning.

In addition to the relevance of topography to Philippine history and culture, an appreciation of the potential and of the restrictions inherent in the contours of the land is essential to planning for the future. In northwestern Luzon, for example, the Ilocos region is predominantly mountains, with only about one-third of the area suitable to agriculture. Compared with

other areas in the Philippines, the Ilocos region would therefore have a smaller potential for agricultural development. Faced with this limitation, one devising the region's agricultural strategy for the coming years will be directed toward "specialization and intensification of high-value, labor intensive cash crops like tobacco, silk and cotton," as recommended in the *Five-year Plan, 1978-1982* of the National Economic and Development Authority. In the mountains, there are areas where soil and climate are favorable to fruit and vegetable production, and development planning in the area accordingly takes this into account.

As in the past, when communities learned the relevance to them of geography and geology, present and future growth will be influenced, to a large extent even determined, by the characteristics of the Philippine archipelago. In the largest islands, Luzon and Mindanao, a combination of earth movements, volcanism, sculpturing by streams and the sea and deposition of the debris of erosion has given rise to a complex landscape. These islands contain lofty and rugged mountain ranges sheltering fertile valleys, plateaus, lakes, volcanoes, swamps, beaches and reefs. Offshore, shelves, trenches, tablemounts and ridges compose variations in the relief of the seafloor. Moderate-sized islands may not have all these elements. Instead some may have a central range of mountains and a coastal plain with occasional reefs offshore. Small islands may consist of only one kind of physiographic element, such as a reef, volcanic pile or a more sturdy protuberance of hard rock over the sea-bottom. The diversity in sizes and landforms, while forming an archipelago of complex beauty, has also given shelter for various forms of life in the past, affording them continuity and abundance, and now provides the foundations for development and survival.

The archipelago is usually subdivided into three geographic parts—Luzon in the north, Mindanao in the South, and the Visayas, an island group, between these two major islands. The three stars in the Philippine flag represent these parts. A fourfold subdivision of the physiography, on the other hand, is recognized by geologists of the Bureau of Mines and Geosciences who are preparing a book on the geology of the Philippines. These consist of three areas with a general north-south direction—called the Eastern Physiographic province, the Central Physiographic province and the Western Physiographic province—and one south-

western province. In this technical classification of landforms in the Philippines, features within each province are traced north to south, from Luzon to Mindanao. This mode is not followed in the survey made in this chapter. Instead, features of each major island will be discussed and, if possible or appropriate, correlated with features found in other parts of the archipelago. This approach to the composition of a picture of the country's landforms is analogous to the freshly accumulating viewpoint of a traveler on a voyage around the Philippines.

A traveler approaching Northern Luzon from the east will be confronted by the imposing and rugged mountains of the Sierra Madre Range at the edge of the Pacific. Nearby, beneath the Philippine Sea, is a subsea plateau known as the Benham Rise, covered by about 2-1/2 kilometers of water. The plateau rises from depths of 5,000 meters. M. Motegi in 1975 suggests that the plateau is related to the middle section of the bend of Luzon known as the Luzon Reentrant, where water depths generally exceed 500 meters. However, south and east of Polilio is a shelf extending as far east as the island of Catanduanes and reaching widths of 50 to 65 kilometers and water depths of 40 to 50 meters Polilio Island, after which the shelf was named, is kidney-shaped, with an area of 654 square kilometers. The west coast of the island consists of a plain that rises westward to highlands which include Mount Malolo, at 329 meters the highest point in the island.

Between the Benham Plateau and Northern Luzon, the seafloor plunges to depths exceeding 5,000 meters in a narrow trough called the East Luzon Trench. The Sierra Madre Range along the northeast coast of Luzon has a northern prolongation which plunges into the sea. This north-south trending ridge, the Cagua Ridge, rises to 3,000 meters above the seafloor. The Philippine Sea therefore contains valleys, mountains and plateaus hidden from human eyes.

Contour of the land

The Sierra Madre Range, which hugs the eastern coast of Northern and Central Luzon, is 565 kilometers long, the longest mountain system in the Philippines. This range, with an average width of 40 kilometers, has peaks ranging from 1,150 to more than 1,850 meters. The northernmost peak is Mount Cagua, 1,158 meters. Mount Anacuano (1,852 meters), the high-

est mountain of the range, is located west of Ildefonso Peninsula in the subprovince of Aurora. The mountains beyond the Antipolo Plateau, visible from Quezon City and Pasig, Rizal, include the angular and lofty Masungit Rock. Cascading waterfalls and mysterious caves, typical features of many mountains of the Philippines, are thus to be found just a short drive away from Metro Manila. The Daranak Falls in Tanay and the Montalban Caves are among these marvelous sights easily accessible from the capital of the Philippines.

The Sierra Madre Range merges with the Central Cordillera, another dominant range in Northern Luzon, to form with the Caraballo Mountains, a Y-shaped mountain system. Located in the province of Isabela and Nueva Viscaya, the Caraballo Mountains is also called the Central Knot of Luzon. Cradled within the arms of the Y, between the Sierra Madre and the Central Cordillera, is the Cagayan Valley, a north-south trending depression about 240 kilometers long and 50 kilometers wide. This fertile valley, one of the rice granaries of the Philippines, is drained by the Cagayan River. The name of the river is derived from the Ilocano word for river, *carayan.* The river has two tributaries which flow from the Central Cordillera, the western boundary of the valley. North of the valley are a number of islands, the Batanes-Babuyan Island group. Three of the five main islands are carved from volcanoes—Calayan (390 meters), Babuyan (1088), and Camiguin (799); the other two, Dalupiri and Fuga, are formed from coralline rock. Didicas rock (244) is a volcanic island reborn as a result of the eruptions in 1952.

The Central Cordillera is the most prominent feature of Northern Luzon. This high and rugged mountain range rises abruptly from the Central Plain of Luzon and stretches for about 300 kilometers to the north coast of Luzon. A broad mountain range, at one point it reaches a width of 100 kilometers—the largest compact upland mass in the Philippines. The Central Cordillera is subdivided into three ranges, namely, the Malaya Range, with elevations reaching 1800 meters; the Central Range, 1800 to 2928 meters; and the Polis Range, 1500 to 2100 meters. Mount Pulog, the highest peak in the Central Range (2928 meters), is the second highest point in the Philippines. Other high mountains in the Central Cordillera are Mount Kapiligan (2670 meters), Mount Pavol (2456), Mount Data (2300), and Mount Santo Tomas (2256). Also found in the Central range is the

highest point in the Philippine highway system, at 2256 meters elevation—even higher than Mount Koscuisko (2229 meters) which is the tallest mountain in the continent of Australia. In the Mountain Trail (Halsema Road), it is not unusual to travel above the clouds along roads strung on mountainsides above dizzying cliffs. Ravines, waterfalls, irregular ridges and contorted peaks reaching for the sky are common in this enchanting upland. In some places here narrow, steep limestone needles pierce the clouds, such as those found around Baguio and Sagada. To combat erosion, Filipinos have constructed huge stairways in the awesome heights of these uplands and turned them into the world's most unique ricefields. The most famous of these are the terraces of Banawe.

The waters of the Central Cordillera are brought to the sea by four main rivers. Two of these, the Magat and the Chico Rivers, flow into the Cagayan Valley where they merge with the Cagayan River. Agno River flows southward to the Central Plain of Luzon, and Abra River flows north to the vicinity of Vigan where it changes course, turning westward along the Abra water gap before pouring into the South China sea. This feature suggests that the river existed in the past before the Ilocos Highlands were formed.

A narrow coast borders the Central Cordillera. This Ilocos lowland, only about 13 kilometers wide, consists of rolling hills and a narrow coastal plain. East of this lowland is the Vigan-Abra Highland with an average elevation near 700 meters and a cluster of peaks ranging from 790 to as high as 1515 meters. At the base of the Three Sisters group (1441 meters), 25 kilometers east-southeast of Candon, Ilocos Sur, is the breathtaking scenery of the Tirad Pass where the 22-year-old Filipino general, Gregorio del Pilar, fought a valiant stand with sixty comrades against a battalion of three hundred Americans on December 2, 1899.

South of the narrow Ilocos coast is the Lingayen Gulf which has also been the scene of important historical events. In this gulf, afloat like an armada of green-covered ships, are the fabled Hundred Islands, a pleasing handiwork of nature produced by a succession of encroachments by the sea which formed the limestone layer and then the uplift of land, caused fragmentation and erosion of the limestone, and finally submergence of the erosional

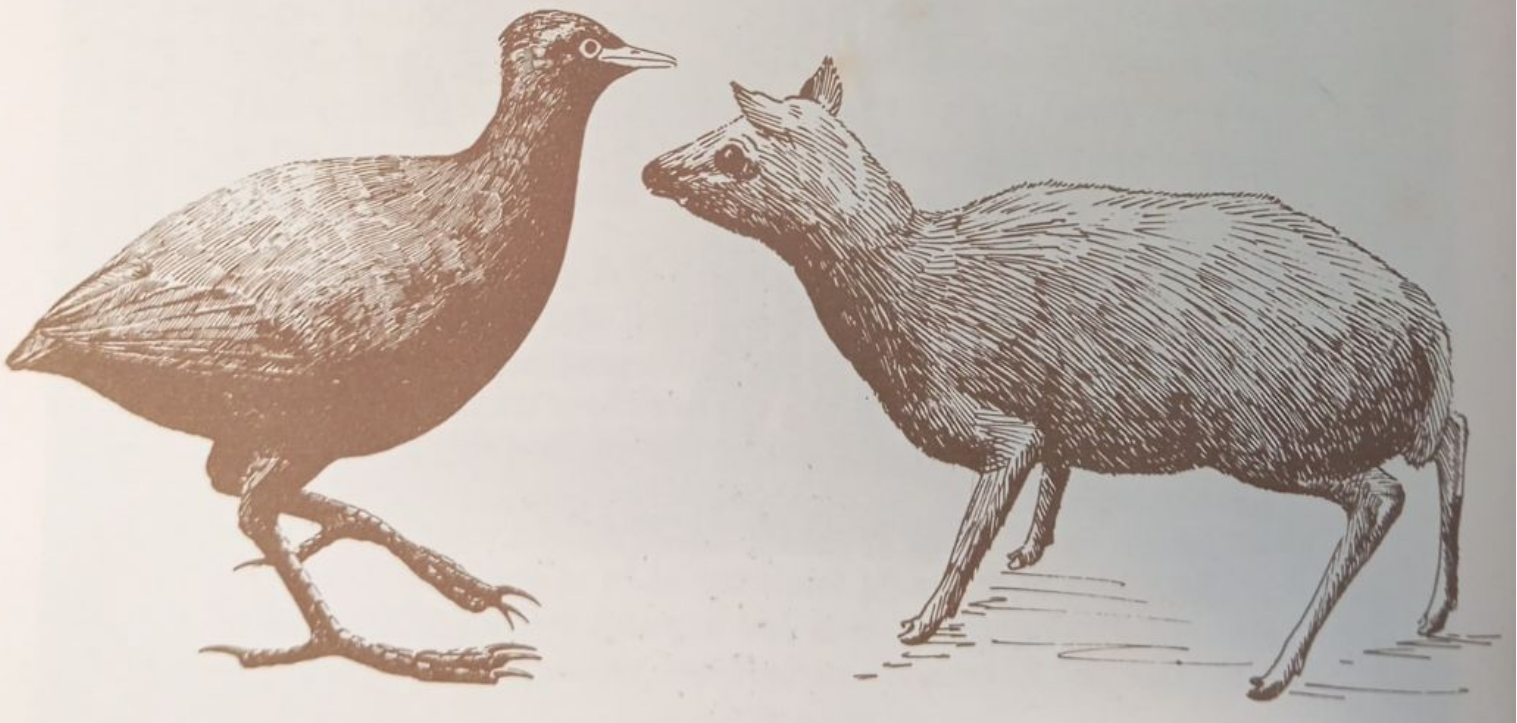
remnants. In the northwest coast of Pangasinan, marine erosion also carved the unusual umbrella rock on the shore of Agno.

The western promontory protecting Lingayen Gulf is the northernmost portion of the Zambales Range which extends southward to the peninsula of Bataan. This range is similar to the highlands of Mindoro and Lubang Island, so much so that some geologists group these areas with the Western Highlands. Four major volcanic centers are recognized within this range. On Bataan Peninsula, Mount Natib (1253 meters) and Mount Mariveles (1388) are the two southernmost volcanic centers. To the north of Mount Mariveles is the historic Mount Samat (553). On these mountains of Bataan thousands of valiant Filipinos sacrificed their lives in defense of their nation during the earlier days of World War II. Farther north and on the east side of the range are Mount Balikibok (1800 meters) and Mount Pinatubo (1745). The western fringe of the range is a coast consisting of a narrow plain, magnificent bays and, in places, sea caves. Offshore, the seabottom plunges into a narrow and deep trough known as the Manila Trench. This north-south trending trench could be traced to as far south as Mindoro where it swings to the southeast. It has a width of 10 kilometers and is generally deeper than 4500 meters with a maximum depth of 5015 meters.

The Central Plain of Luzon, lying between the Zambales Range and the Sierra Madre Range, is the most extensive flatland of the Philippines. From the foothills of the Central Cordillera it extends south for 150 kilometers to the shores of Manila Bay. This fertile plain is about 60 kilometers wide. Towering alone in the central part of the plain is Mount Arayat, a volcanic mountain, which rises to 1030 meters.

The Central Plain is drained at its northern end by the Agno River which flows into the Lingayen Gulf, and at the south by the Angat and Pampanga Rivers which flow into Manila Bay. Angat River has its headwaters in the Sierra Madre Range. Calculations on the load of the Angat River by Jose M. Feliciano and Cornelio C. Cruz in 1933 have shown that the erosion rate of the drainage basin of Angat River is about three millimeters per year. This rate is 10 to 100 times higher than measurements in Europe and North America but it is comparable to the rates measured in Indonesia as reported by Reinaut V. W. van Bem-

BAMBUS ARUNDO — Blanco.
BAMBUSA ARUNDINACEA — Willd. — Kunth.

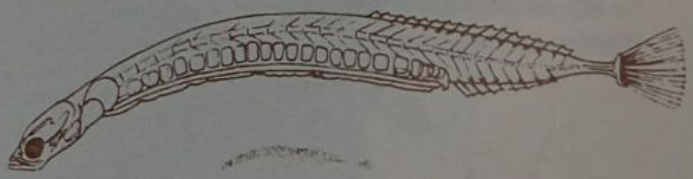


The bamboo (overleaf) and the sugarcane (left) are members of the grass family that thrive in lowland areas of the Philippines.

Philippine forests shelter a variety of wildlife including the megapode, tabon bird (facing page, bottom left), the mouse deer (facing page, bottom right) and seloputo owl (above).

*Various flowering plants such as the orchid (facing page) and the Kingfisher (**Halcyon chloris gullaris**), above, contribute to the hues of the Philippine habitats.*

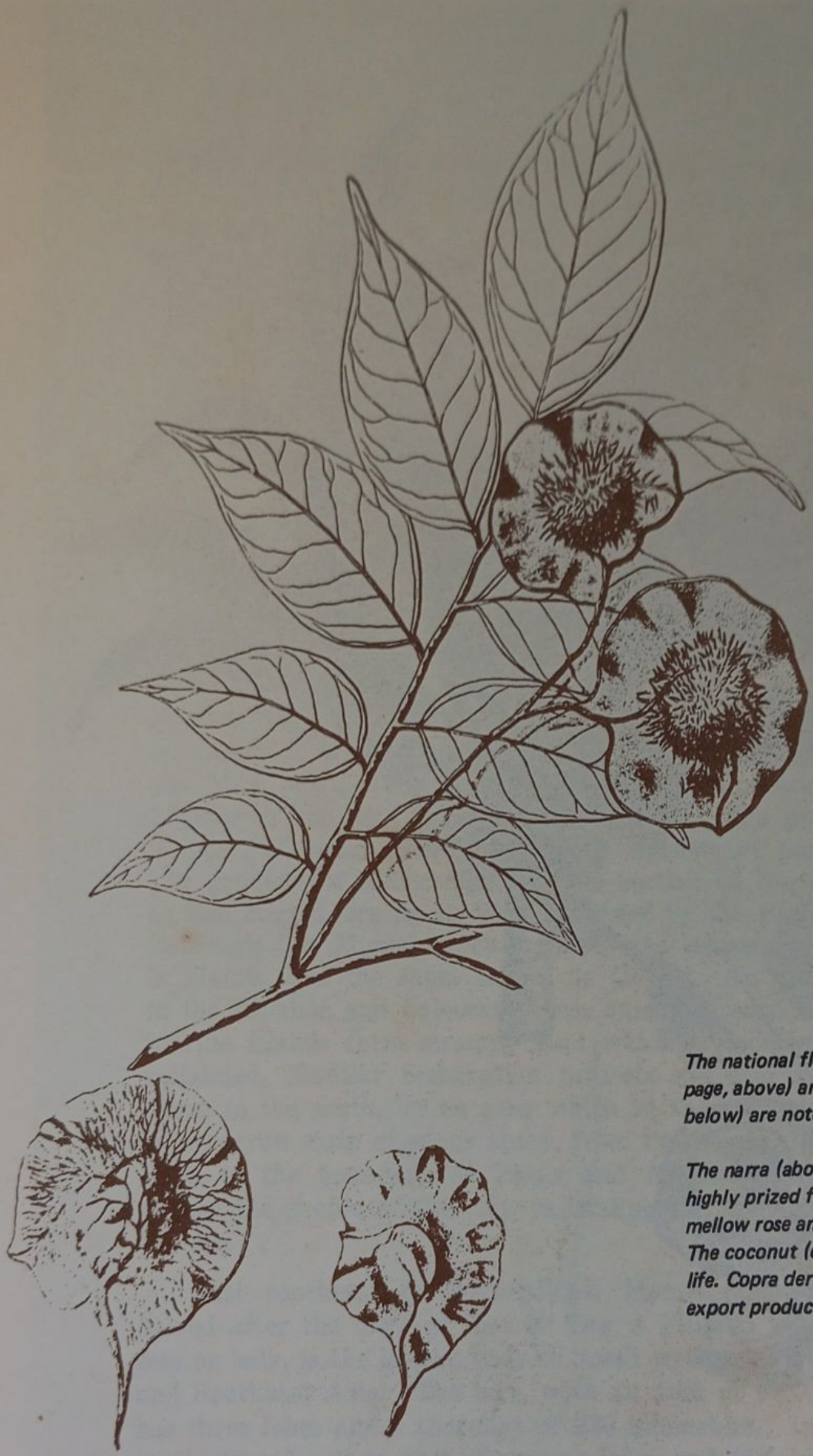
*The worlds' smallest fish in terms of length, **Pandaka pygmaea**, (right, above) and, in weight - The **sinarapan** (right, below) flourish in Philippine waters. The worlds largest fish, the whale shark, also lurks in the tropical seas of the Philippines.*



NICTHANTHES SAMBAC.—LINN.

JASMINUM SAMBAC.—AIT.

JASMINUM BICOROLLATUM.—ROXBURGH.



The national flower, sampaguita (facing page, above) and the ilang-ilang (facing page, below) are noted for their fragrance.

The narra (above), the national tree, is a highly prized fine grained hardwood with mellow rose and yellow tones.
The coconut (overleaf) is a veritable tree of life. Copra derived from its nut is a primary export product.

melen in 1948. The erosion rate is presumably higher, with the extensive deforestation of large areas in the Sierra Madre Range. The Angat River joins the Pampanga River; north of this confluence is a large tract of swampy land (270 square kilometers) known as the Candaba swamp, which covers areas in the provinces of Bulacan and Pampanga. According to Mario Sandoval and Francisco Mamaril, Jr., the Candaba swamp probably is the result of a combination of the following factors: 1) very low stream gradient; 2) low elevation of the area; and 3) shallowness of the water table in the area.

Southward, the Candaba swamp merges with a delta that rims the eastern side of Manila Bay. This delta, on which is situated the City of Manila, rises eastward to the Quezon City Plateau which is underlain by tuff, a rock consisting of consolidated volcanic ash. The Manila delta is broadest, reaching a width of about five kilometers, at the confluence of the Pasig River and the San Juan River. The relatively flat delta, reaching an elevation of about three meters in the districts of Makati, Sta. Mesa and La Loma, is interlaced by an intricate pattern of tributaries and distributaries called esteros. The principal city of the Philippines therefore actually consists of many islands. The grounds of Malacañang, in the section of the city known as San Miguel, are on an island bounded by the Pasig river, the Estero de San Miguel which is one of the largest of such canals in Manila, and the short Estero de Uli-Uli. To the northwest, in the Malabon and Caloocan areas, numerous sand bars and estuarine islands form swampy land which is increasingly being reclaimed. Similar reclamation projects are also being undertaken to the south, on an area which in the past was bordered by a narrow strip of sandy shore, from Parañaque, through Baclaran to the boundary of Pasay and Manila. These projects change the profile of the city, expanding the land areas toward the sea.

Just southeast of metropolitan Manila, Laguna de Bay, named after the town of Ba-i or Bay, a Pilipino word for princess or lady, is the largest body of fresh water in the Philippines and Southeast Asia. The lake, with an area of 90,000 hectares, has three lobes and a shoreline of 220 kilometers. In the north-south direction it is 40.8 kilometers long, and 45.6 kilometers in the east-west direction. About 10,000 fishermen and their fa-

milies obtain their livelihood from the lake, which yields an annual catch estimated at 40,000 tons.

The lake has a drainage area of 3,264 square kilometers from which an average of four billion cubic meters of water flow into the lake. Of this amount, three billion cubic meters are discharged into Manila Bay through its only outlet, the Pasig river, which cuts across the heart of Manila. The remaining one billion cubic meters seep into the ground to recharge underground reservoirs known as aquifers, but the bulk of this amount returns to the air by evaporation.

The Laguna de Bay is relatively shallow in most places, its average depth being only 2.8 meters. The lake bottom, however, plunges to depths exceeding 18 meters near Diablo pass between the Binangonan peninsula and Talim Island, in a channel connecting the lake's Marikina lobe and its Tanay lobe. The lake level, only about 1-1/2 meters above the mean sea level of Manila Bay, rises occasionally from two to four meters during the rainy season and during periods of intense rainfall that accompany typhoons. At certain times, however, high tides in the Manila Bay exceed the lower water level of the lake. At such times the flow of the Pasig River is reversed, bringing salt water into the lake. This intrusion of salt water has raised the amount of dissolved salts in the lake to as much as 5000 parts per million, a level in excess of the quantity recommended for irrigation and water supply.

Several elements in the architecture of Central Luzon contributed to the origin of this large body of fresh water. The eastern margin is bounded by the Sierra Madre range while the south and southwest are on the edge of highlands formed by relatively young volcanoes. Arching of the rocks underlying Manila, Western Rizal and Western Laguna owing to movements which produced the Marikina fault eventually blocked the drainage and impounded vast amounts of water.

This body of water and its outlet, the Pasig river, have been the setting of many historical events. Tagalog kingdoms were established around the lake. Today, the lake is an important natural resource whose potential has barely begun to be realized. In the future, it will serve as a source of water for Metro Manila and for irrigation. Some experts have also proposed using the

lake to control floods. On account of its tremendous value as an important natural resource, constant painstaking care must be exercised to prevent industrial pollution and salt water intrusion from Manila Bay, the two main causes of the deterioration of the water quality. Increased siltation caused by floodwaters pouring into the lake must also be guarded against. Otherwise, a lake born hundreds of thousands of years ago may perish within historic times.

A volcanic field lies in the region west and south of Laguna de Bay. The volcanoes in this area include Mount Makiling (1090 meters), Mount Cristobal (1470) and Mount Banahaw (2177). Hot springs at the foot of Mount Makiling attracted early Spanish explorers, whose passion for them led to the construction of Roman baths in the town of Maynit (now Los Baños) in 1671. Today, the Makiling-Banahaw region is being developed for geothermal energy, earth heat which can be harnessed to generate electricity.

A world-renowned caldera, Lake Bombon and Taal Volcano together, is located southwest of Laguna de Bay. The lake has an area of 330 square kilometers; within it is a small active volcano, which in turn has another lake within its crater. Taal Volcano, one of the lowest volcanoes in the world, and its scenic lakes may be viewed from the Tagaytay Ridge on the north side of the caldera. The ridge, with an average elevation of 600 meters, includes Mount Batulao (693 meters) in the west and runs to Mount Sungay in the east.

The volcanic terrain of Cavite, Batangas, Laguna and Quezon forms the Southwest Luzon Upland. The coast on the southern edge of this upland, at Malbrigo Point in Batangas, offers striking scenery consisting of a succession of broad marine terraces that rise gradually up to 180 meters above sea level. On the northern part of the upland is another stretch of coast, running through a spit jutting into Manila Bay and on which Cavite City is built. The eastern boundary of the upland merges with the southern extension of Sierra Madre Range, which projects southward into the Sibuyan Sea as the Bondoc Peninsula. The peninsula is underlain by folded rocks that reach 350 meters in elevation. Drowned streams in the peninsula indicate recent submergence of the area.

Southwestern Luzon is a peninsula connected with the rest of Luzon along Calauag. Uplifted terraces and a low elevation of land separating Calauag Bay from Ragay Gulf suggest that a continuous channel existed from Lamon Bay to Sibuyan Sea in the past.

Dormant and active volcanoes form the most prominent features on the Bicol plain in the peninsula of southeastern Luzon. These volcanoes, aligned parallel to the southeast trend of the Bicol Peninsula, are Mount Labo (942 meters), Mount Isarog (1976), Mount Iriga (1159), Mount Malinao (1657), Mount Mayon (2421) and Mount Bulusan (1553). The most famous of these, Mayon Volcano, whose proudest feature is its almost perfect cone, derives its name from the Bicol word for beautiful—*magayon*. This volcano has been erupting regularly every 10 years since 1814, the year of its worst recorded eruption, which killed about 12,000 people and buried vast areas like Cagsawa and Budiao.

Lake Buhi, near Mount Iriga, is believed to have been formed when the volcano erupted in 1641. This lake, at an elevation of 100 meters above sea level, is famous for tabios or sinarapan, the smallest commercial freshwater fish in the world.

The Bicol Plain or Bicol Basin, lying west of the volcanic belt, is drained by the Bicol River. A coastal range of low mountains and hills bounds this plain on the southeast beside the Ragay Gulf. Within the basin are limestone caves, such as the Libmanan Caves, adorned by stalactites and stalagmites, icicles and pillars of calcium carbonate. Elsewhere in the limestone areas of Bacon are caves that contain prehistoric artifacts.

The eastern, irregular coast of the Bicol Peninsula holds numerous bays. San Miguel Bay shows at least five traces of old shorelines, an indication that the Bay emerged from the sea. Caramoan Peninsula, adjacent to the Bay, is an interesting terrain underlain by old rocks. The south end of the Bicol Peninsula, shaped like a hook, protects Sorsogon Bay.

East of the Caramoan Peninsula, the bean-shaped island of Catanduanes stands on the Polilio Shelf. It is about 60 kilometers long in the north-south direction and 40 kilometers in the east-west direction. Only seven per cent of the land area of about 1,469 square kilometers are lowlands; these are in the

southern part of the island. In the areas along the shore, wave action had sculptured limestone into pedestals and stacks. Caves, sinkholes and depressions are also found in limestone areas. Near Virac and Calolbon, caves hoard large guano deposits.

The highlands of Catanduanes consist of three northwest trending mountain chains—the northern, the eastern, and the southwestern blocks. The highest point on the island is 803 meters high, located within the southwestern block. A limestone ridge within the southwestern block has been eroded to form hills shaped like haystacks similar to those found in Bohol.

Mindoro, the seventh largest island in the Philippines, with an area of 9,830 square kilometers, is another bean-shaped island separated from the island of Luzon in the north by the Cape Verde passage. The island is set apart from the islands of Marinduque and Romblon by the Tablas Strait in the east and from Palawan by the Mindoro Strait in the southwest. Apo Reef, a magnificent double atoll whose water sparkles with rainbow-hued fishes, corals and marine life, is found west of Mindoro.

A central range known as the Central Mindoro Divide runs through the length of the island. Among the loftier peaks in this range are Mount Halcon (2505 meters), Mount Burburungan (1574), and Mount Baco (2488). Steep valleys and waterfalls are common features of the eastern side of the range. In the northeast, Lake Naujan, 98 square kilometers of serene waters, is surrounded by volcanoes in the north, east and south. The lake, teeming with fish and waterfowl, is the breeding ground of the Mindoro crocodile. To the north is Puerto Galera, a sheltered and complex inlet that offers a dramatic view of the soaring peaks of the central range and coral beaches nearby. Young volcanic cones and plugs form rounded hills and promontories on the east coast.

Marinduque is a round-shaped island east of Mindoro and separated from the Bondoc Peninsula by the Mogpog Pass. It is connected to Luzon by a strip of land that is actually part of its contour although its surface is beneath 75 meters of water. If the sea were to recede by this much, overland travel between Marinduque and Luzon would be possible. The island, 899 square kilometers in size, is mountainous, with peaks ranging from 558 to 1157 meters high. The island is crossed by the Boac River whose

waters originate in the southeast, flow northwestward and empty into the Sibuyan Sea. Narrow pockets of alluvial flats hug the mountainous core of the island. In the southeast part of the island stands the young volcanic mountain Mount Marlanga (1157 meters), the highest mountain in the island.

The Sibuyan Sea is a basin that separates Luzon from the islands of the Visayas. The sea encloses the islands of Tablas, Romblon and Sibuyan, all of the province of Romblon. The northern part of the Sibuyan Sea lying between Romblon, Masbate and Marinduque is elliptical in shape, with a northwest trend. The bottom of the northern Sibuyan Sea Basin descends to depths of more than 1825 meters. The southern part of the basin is between Panay, Romblon and the Visayan Shelf. The western margin of this portion of the Sibuyan Sea, adjoining Tablas Island, is very steep; here, close to the island, the bottom descends to more than 1370 meters. The island of Tablas is aligned with the Buruanga Peninsula of Panay. Sibuyan island in the middle of the Sibuyan Sea is rugged, with a narrow coast. Uplifted marine terraces are in several parts of the island.

Masbate on the eastern side of the Sibuyan Sea is an L-shaped island, its two legs trending to the southeast and to the southwest, parallel to two of the main regional trends of the Philippines. The northeast corner, or the apex of the L, is rugged and mountainous. The northwest leg to Bugui point is a plateau of limestone with conical hills and sinkholes. Raised marine terraces up to at least 200 meters may be observed in this island. Ridges in the western part of Masbate have a northeast trend parallel to the coast while those on the other side of the island are aligned with the east coast. The southwestern side of the main leg of the island is a plain and piedmont terrain. The largest rivers of Masbate, Malbug and Asid, flow into the shallow Asid Gulf. North of Masbate are the spindle-shaped islands of Ticao and Burias whose northwest trend reflects the folding of underlying rocks and the trend of the nearby Philippine fault.

A broad shallow shelf stands less than 50 meters under the Visayas sea between the islands of Masbate, Ticao, Negros, Panay and Guimaras. If the surface of the sea were lowered by 50 meters, a large island would be uncovered by the receding waters. During the past ice age large amounts of sea water were with-

drawn from the oceans and locked in vast sheets of ice that covered large parts of Europe, Asia and North America; when that happened, the undersea island might indeed have surfaced.

Panay, the westernmost island in the group resting on the shallow shelf, is roughly triangular in shape. The northern tip of the triangle is the Buruanga Peninsula which extends southward to a crescent-shaped cordillera that follows the western coast for 120 kilometers along a north-south direction. This western cordillera is about 24 kilometers wide in the central part and tapers toward the north and south. This imposing mountain range has an average elevation of 900 meters and reaches its highest points in the summits of Mount Mangtud (2049 meters) and Mount Madlum (2188). The western edge of this range is steeper than its eastern slopes; hence, only a narrow coastal plain is found on the western side of Panay.

Another mountainous region, trending northeast to southwest, exists along the eastern side of Panay. This region is 55 kilometers long and has its maximum elevation in the northeast end, at Mount Agudo (834 meters). Volcanic cones and mountains, like Mount Bayaso (450) adorn the landscape of this eastern cordillera.

The Central Lowland, also known as the Iloilo Basin, separates the two mountainous regions. The northern part of the basin opens toward the Sibuyan Sea while the southern part opens toward the Iloilo Strait. A divide in Central Panay forms a partition between the two main complex drainage systems of the basin. The Sibalon, Narao, Tanian, Jaro and Jalaur Rivers drain into the Iloilo Strait; the Aklan and Panay river systems discharge into the Sibuyan Sea. Jaro and Jalaur Rivers have leveled the Iloilo plain. Capiz rests on a deltaic plain built by the Panay River. Deltas are also developed in the Aklan River and the Sibalom River. Mangroves and nipa trees thrive on the coasts along the Central Lowland.

Negros, the fourth largest island in the Philippines and shaped like a boot, lies between Panay and Cebu. Volcanic mountains guard the northern and southeastern ends of the island. The active volcano, Mount Kanlaon (2438 meters), found in the northern half, is the highest mountain in the island. Two inactive cones, Madalagan (1879) and Silay (1535), lie north of Kanlaon.

A complex series of mountains running close to the east coast links the volcanic terrain in the north to the inactive Magaso Volcano (also known as Cuernos de Negros), 1903 meters high, at the southeast end of Negros. The eastern edge of the range is steep, so that only a narrow coastal plain was developed in the east. The western side slopes gently into a broad western plain, which is utilized for sugar production. This fertile plain was built with deposits from the volcanoes and rivers that come from the eastern range. The southwestern part of Negros consists of hills and elevated land generally exceeding 150 meters in elevation, named the Tablas Plateau after the Tablas River which drains it. Mount Malapantao, on the northwest end of the plateau, attains a height of 619 meters.

Tañon Strait, generally exceeding 200 meters in depth, and at places more than 500 meters, separates the island of Cebu from Negros. The long and narrow island of Cebu has a trend almost parallel to the eastern coast of Negros. It has a mountainous core that extends for about 160 kilometers along the length of the island. This central range reaches its highest point on Mount Cabasalan (1013 meters), in the central part of the island. Most peaks have elevations below 750 meters. Nestled within the central part of Cebu, in Toledo City, the awesome pits of Atlas Consolidated Mining Company form the biggest copper mine in Southeast Asia.

Only narrow coastal plains are found around the island. As in other islands of the Visayas, several elevated marine terraces are found in Cebu. Cebu City and Mactan Island are underlain by these uplifted marine terraces. The largest plain in the island is situated at the northern end of Cebu, around the town of Medellin. In the south, the drainage patterns of the Argao and Dalaguite rivers reflect the influence of underlying rocks and structures. The westward development of the Argao river resulted in the capture of other streams (stream piracy). The northeastern coast of Cebu is bounded by the Camotes Sea while the southeastern is bounded by the Bohol Strait. Several reefs are interposed in the strait, which lies opposite Cebu City, between the island provinces of Bohol and Cebu.

The double barrier reef north of Bohol is a rare feature in the Indopacific region. The outer barrier consists of three units, 22 to 26 kilometers long, separated by narrow passes. The outer

reef, with an average width of 2.8 kilometers, is located nine kilometers (in the northwestern part) to 22 kilometers (in the eastern part) from the shore. The sea bottom drops to depths more than 400 meters less than two kilometers beyond the margin of the outer barrier. The inner barrier, 5-1/2 to nine kilometers from Bohol, is more fragmented than in the outer barrier but the central part, Calituban reef, 22 kilometers long and 2.8 kilometers wide, is an unbroken single unit. A channel, 3.7 to 6.5 kilometers wide with a maximum depth of 37 meters, separates the two reefs. The inshore channel between the inner barrier and Bohol reaches a maximum depth of 36 meters. The landward portion of this channel is fringed with mangroves and mudflats. This unusual barrier reef developed because of the favorable tidal and current conditions in the Bohol Strait coupled with the submergence of the reef platform.

Bohol is an oval island whose southern part is mountainous, though cut up by deep gullies and gorges. The northern part is a region of lower relief with extensive tracts of level land, broad valleys and rolling hills. In this area, between Guildulman and Ubay, a unique landform developed into almost perfect domes resembling mounds of chocolate. The "Chocolate Hills" of Bohol, described by Warren Dupre Smith in 1925 as "haycock hills," rest on a level plain about 140 meters above sea level. Three height measurements of the hills above sea level are recognized; these are at 190 meters, 230 meters and 270 meters. The hills consist of limestone, a rock consisting of carbonates like those that compose the framework of coral reefs. In north central Bohol, the land also has a rolling topography; but the rock underlying the hills in this section is of a different kind, so that these hummocks did not develop into domes like the Chocolate Hills.

Juan S. Teves, in 1947, suggests that the hills were formed during three episodes of uplift of the area as indicated by the three levels of heights in the hills. During the early stages of uplift, a rolling topography, similar to that in north central Bohol, developed and gave rise to the initial shape of the hills. As slow uplift continued, erosion also progressed slowly, in this way retaining the initial form and eventually carving out the domes now known as the Chocolate Hills. A rare combination of rock type, climate, slow earth movements and erosion therefore produced the unique and visually pleasing topography in a part of Bohol.

Along the south coast of the island of Bohol, limestone hills rise abruptly to several hundred meters. Caves were developed in these hills as ground water dissolved fractured zones in the limestone being elevated by earth movements. The numerous caves near the coast contain guano, a useful raw material for fertilizer. Similar guano-bearing caves are found in Batangas, Masbate, Mindoro, Iloilo, and Palawan.

The island of Leyte forms the eastern boundary of the Camotes Sea. The 50-meter underwater contour connects Bohol with this island along the shallow Danajon Bank. The 50-meter contour also encompasses the islands of Biliran and Samar, such that during the low-water periods in the geologic past these islands would merge into a large one, as did Panay, Masbate, Negros and Guimaras on the Visayas Shelf.

Leyte possesses a complex topography of mountains, lowlands and bays. A central range trending N 30° W runs parallel to the elongation of the island. The highest point in the island, about 1,300 meters, is found in this range. The Philippine fault passes through this range. Uplifted marine terraces reaching as high as 150 meters are found in southern Leyte, in the southern extension of the range. There are also highlands in the northwest corner and in the northwest projection known as the Calubian Peninsula. This peninsula shows evidence of local earth movements. Marine terraces up to 120 meters in elevation are exposed in the area south of Rabin Point. However, drowned streams and bays on the western side also indicate recent submergence. This produced beautiful bays, such as San Isidro and Arevalo Bays whose picturesque gateways are composed of ramparts of white limestone and sandstone. Adorning the bay are grass-covered hills that roll toward a mangrove-bordered shore. In the southern end of this peninsula, time had built a delta toward Ormoc Bay.

Tacloban, the capital of Leyte, rests on the most extensive plain on the island. This plain forms part of Leyte Valley lying between the Central Range and the Northeastern highlands. Rivers flowing to the northeast and east, originating from the Central Range, cross Leyte Valley. This northwest trending valley may be a landmark extension of the Ticao trough in the northwest. The structural trendlines of the Central Range may also be traced

toward Burias and Ticao Islands in the northwest and to Surigao in the island of Mindanao in the south.

San Juanico Strait separates Samar from Leyte, and another strait called San Bernardino, with a maximum channel depth of 160 meters, separates Samar from Luzon. Samar, the third largest island in the Philippines with an area of 13,272 square kilometers, is the easternmost island of the Visayan Island group. Its name, derived from the Visayan word meaning "to cut," aptly describes the topography of the island which is rugged and deeply dissected by streams. There is no prominent mountain range but mountains that are low and rugged span the island from coast to coast. The highest peak, at 896 meters, is in the north central part of the island. The most extensive lowland area sprawls in the northern part of the island, where hills reaching a height of 300 meters are found. The northeastern coast is moderately sinuous, with delta flats and reefs that protect the shore from the onslaught of Pacific Ocean waves. Embayed and irregular shorelines on the eastern coast, in the vicinity of Taft and Dolores towns, indicate submergence. The southern part is high and rugged in most areas. A peninsula consisting of a coral ridge 43 kilometers long, 270 to 590 meters wide and 120 meters high, projects from the southeastern tip of Samar, south of Matarinao Bay.

The highlands of Samar extend southward into a submarine platform on which the islands of Homonhon, Dinagat and Siargao rise from the sea floor. Further southward, this platform rises to form the Diwata range of Eastern Mindanao.

The Visayan region, although comprised today of numerous islands that are of moderate sizes, contained more extensive land areas in the past, during periods of low sea level. An eastern range may have connected Mindanao with Luzon but earth movements and erosional processes, as well as transgression by the sea, have broken up this eastern seaboard range. Marine terraces are common around islands of the Visayas and these record the progressive uplift of the land previously submerged.

Like the island of Luzon, Mindanao, the second largest island of the Philippines with an area of 95,600 square kilometers, shows a wide variety of landforms. The island may be divided into Eastern Mindanao and Western Mindanao. Eastern Mindanao, the

largest compact landmass of the archipelago, is distinguished from the Western part by a narrowing of the land along Panguil Bay and Pagadian Bay. Surrounding the island are several marine basins—the Mindanao Sea to the North, between Bohol and this island; the Philippine Sea to the east; the Celebes Sea in the South; and the Sulu Sea in the Northwest. The cold, dark and abyssal bottom of the Philippine Deep, a trench with a north-south trend, extends from 4° to 15° N along the eastern side of the island. The deepest part of the trench, at 11,800 meters below sea level, lies opposite northeastern Mindanao.

Parallel to the trench, along the irregular eastern coast of the island, rises the Diwata range which stretches for 350 kilometers from Surigao to Davao. This rugged mountain range is part of the Pacific Cordillera that may be traced northward to Samar and perhaps further north to the island of Luzon. Peaks range from 400 to 2,250 meters; Mount Kampalili (2,250 meters) opposite Caraga Bay is the highest mountain in the range. Toward the south, this range plunges beneath the sea to form the Talaud ridge. In the northern part of this range lies Lake Mainit which is shaped like a human foot. This lake, 25 meters above sea level, has an average width of 7-1/2 kilometers and a length of about 20 kilometers.

The Diwata Range flanks the broad, flat Agusan-Davao Valley and is about 190 kilometers long and 40 to 50 kilometers wide. The 175-kilometer Agusan Valley in the north is separated from the Davao coastal plain by a divide less than 200 meters in elevation. The Agusan river draining the northern valley, one of the longest rivers of the Philippines, flows into Butuan Bay while the Tagum river in the Davao Valley flows southward into the Davao Gulf. The City of Davao which sprawls on 244,000 hectares of the Davao Valley is the biggest city in the world, in terms of land area. The sea beneath Davao Gulf is shallow but it deepens further south into the Sangihe trough which lies beside the Talaud ridge.

The western margin of the Agusan-Davao valley are hills that eventually merge with the north-south trending Central Cordillera of Mindanao which stretches for 190 kilometers. This range has many impressive peaks but the most important one is Mount Apo in the southern part. The cloud-capped heights of this mountain,

a nonactive volcano, reach 2,965 meters, the highest point in the Philippines.

In the Northern part of the Central Cordillera the western side of the range merges with a complex terrain of lakes, volcanoes and a plateau called the Bukidnon-Lanao Plateau. This highland is bounded by the irregular coast that forms the southern side of the Mindanao Sea. Streams tumbling over the northern edge of this plateau form impressive and scenic waterfalls, including the Maria Cristina falls. Also found along the north coast are seven levels of wave-cut terraces which reach an elevation of 360 meters above the sea. These terraces record the uplift of the plateau. Camiguin Island, a volcanic island in the Mindanao Sea, may be considered part of the Bukidnon-Lanao Plateau's volcanic terrain.

The southwestern side of the highland is bounded by the Illana bay; to the south lies the marshy plains of Cotabato Valley. The broad highlands of the Bukidnon-Lanao Plateau extend for 170 kilometers in the east-west direction and 130 kilometers in the north-south direction. The plateau has an average elevation of 600 meters above sea level, but volcanic mountains tower above the elevated plain. The volcanic mountains include Mount Katanglad (2379 meters), Mount Kalatunga (2285), Mount Ragang (2815) and Mount Pinapayungan (2815). A radiating pattern of gullies and ravines has been sculptured by streams rushing down from these mountains. Nestled within the plateau are the pleasant waters of several lakes, the largest being Lake Lanao. This picturesque lake, perched 660 meters high, is 32 kilometers by 17 kilometers in its longest and widest sections. The lake was formed when lava flows dammed a pre-existing valley. The lake is drained by the Agus River which has cut gorges on its way and cascades into the Maria Cristina Falls before flowing into Iligan Bay. The Agus river will further serve the energy need of Mindanao when the hydro-electric projects that will harness the power of the river are completed.

Cotabato Valley, with a length of 140 kilometers and a maximum width of 85 kilometers, is cradled by the Bukidnon Plateau in the north, the Mindanao Central Cordillera in the east and the Daguma range in the southeast. Lowlands that surround the Sarangani Bay in the southeast may be considered an extension

of the Cotabato Valley. The Mindanao River which drains the valley flows to the Moro Gulf to the west through a constriction resulting from the convergence of the Daguma Range with the Bukidnon-Lanao Plateau. The Carmen lowland in the northern portion of the valley is drained mainly by the Mandaya and Malitbog rivers that empty into the Ligwasan Marsh. Northwest of this marsh is another swampy area known as the Libungan Marsh. Numerous ponds are found in this valley; the largest of these inland bodies of water is Lake Buluan, at about 50 meters elevation, on the southeastern side of the valley. Folds in the underlying rocks have formed several smaller valleys within this lowland of Cotabato; these include the Allah, Koronadal and Alip valleys.

The Daguma Range to the southwest of Cotabato Valley is a northwest trending range with a rugged southwest margin fringed by a limited coastal plain along the Celebes Sea. The range extends for 180 kilometers from Illana Bay and Cotabato City in the northwest to the Sarangani Bay in the southeast. The northern portion of the range is a plateau with elevations of 300 to 350 meters above sea level. The terrain becomes rougher and mountainous south of Mount Blik (1200 meters). The central portion of the range is the Kulaman tableland, about 75 kilometers long and 25 kilometers wide with an average elevation of 1400 meters. Caves and rock shelters in this plateau were used as burial sites by Filipinos of ancient times. Parker Volcano is located in the southern end of the range. Manghan Lake, at 1200 meters above sea level, is a crater lake of this volcano. Also believed to be volcanic in origin are Lake Sebu and two smaller lakes at about 690 meters above sea level.

The Western part of Mindanao looks like an elephant's head. The northern portion is volcanic terrain which presumably belongs to the same volcanic province forming the Bukidnon-Lanao Plateau in Eastern Mindanao. This volcanic terrain consists of lofty peaks which are the highest points in Western Mindanao, namely Mount Dapiak with an elevation of 2617 meters and Mount Malindang, reaching 2425 meters above sea level.

The hills south of the volcanic terrain follow a trend parallel to the elongation of the Zamboanga Peninsula. In the Malangas-Kabasalan area, gently rolling hills, mostly around 150 meters in

elevation, form a plateau adjoining the Sibuguey River plain. The Zamboanga peninsula has a trend parallel to the elongation of the island of Cebu in the northeast. The peninsula has a central range flanked by narrow coastal plains mainly underlain by uplifted coral reefs. Zamboanga City is on a small coastal plain at the southern end of the peninsula. The shelf south of the peninsula under the Moro Gulf is shallow. North of the Peninsula, the sea bottom descends rapidly into the abyss of the Sulu trough.

Basilan Island, 18 kilometers south of Zamboanga City across Basilan Strait, is volcanic. It forms the northeastern end of a chain of volcanic islands that extends to the southwest as far as the Sulu Archipelago. The highest peak, Basilan Peak at the center of the island, reaches 1011 meters in elevation.

The Sulu Archipelago, a northeast trending chain of islands, stretches for 320 kilometers from the Sibutu island group in the southwest corner of the Philippines. The islands of the archipelago rest on a ridge that connects northeast Borneo with the Zamboanga Peninsula. The ridge rises from the great depths of the Sulu Sea in the northwest end of the Celebes Sea in the southeast. The archipelago is a double chain of islands. The northern chain, consisting of the Pangutaran and Pilas groups of islands, is made of coral reefs of low relief undergoing various stages of development. Parallel to this northern chain is another, which is predominantly volcanic and with associated coral reefs. Tawi-Tawi, whose elongation follows the trend of the archipelago, is in the southern chain but it has a greater variety of rocks compared with the other islands. Tawi-Tawi has a central range in the northeastern half of the island. This northeast trending range reaches an elevation of 320 meters in Mount Baluksampak and 317 meters in Mount Budbas. The largest island in the Sulu Archipelago is Jolo which is predominantly volcanic. Bud Dajo, an active volcano, lies within this island. Scattered in the archipelago are a variety of coral reefs with abundant marine life of breathtaking beauty and color. Hanging reefs, atolls and table reefs form an underwater wonderland which endlessly fascinates scientists, artists as well as laymen.

Sulu Sea, between the Sulu Archipelago and Palawan, is the largest internal body of water in the Philippine Archipelago.

The southwestern edge of the basin, within Philippine territory, is shallow with a number of small islands. This area is undergoing active exploration by Philippine oil companies. A northeast trending ridge called the Cagayan de Sulu ridge divides the basin into the Northwest Sulu Basin and the Southeast Sulu Basin. The ridge connects the volcanic island of Cagayan de Sulu with the coral islands of Tubataha, Arena, Cavili and Cagayan. The ridge extends for 520 kilometers from the southwestern shelf of the Sulu Sea to the southern tip of Panay. The Northwest Sulu Sea basin is shallower than the other half. The former reaches depths of more than 2000 meters; the central area of the Southeast Basin, on the other hand, varies in depth from 3800 meters to 4300 meters, with the maximum depth at 5560 meters in the northeast corner of the basin. The northern edge of the basin is a shelf with an area of about 32,000 square kilometers; known as the Calamian-Cuyo Shelf, it has a depth of 55 to 110 meters. It covers the area between Panay, Mindoro and Palawan.

The island chain comprising the province of Palawan in the southwestern part of the Philippines forms a northeast trending ridge between the Sulu Sea and South China Sea. The chain rests on a shallow submarine ridge that extends for 720 kilometers from North Borneo northeastward to the Calamian-Cuyo Shelf. Parallel to this ridge, 65 to 100 kilometers from the western coast of Palawan, is a trough whose maximum depth of 2890 meters is reached west of Balabac Island. This trough becomes shallower toward South China Sea in the northeast end and toward the Sunda Shelf in the southwest. West of Palawan and north of the trough is a tablemount known as the Recto Bank. The Recto Bank, about 195 kilometers long in the north-south direction and 190 kilometers wide in the east-west direction, has an area of 37,000 square kilometers.

The main island of Palawan is mountainous, 415 kilometers long but narrow, with an average width of 40 kilometers. The coast is irregular, with very narrow shores that rise within a short distance in the mountainous backbone of the island. The island becomes narrower at two places, along the lines from Ulugan Bay to Honda Bay and from Island Bay to Malanut Bay. The elevations are generally lower in these portions, hence these saddles and necks subdivide the island into North, Central and

Southern Palawan. These physiographic subdivisions also reflect fundamental differences in the subsurface rocks. The northern part is mainly underlain by ancient metamorphic rocks, the central portion by crystalline rocks rich in iron and magnesium, and the south predominantly by younger folded sedimentary rocks. These differences in the subsurface have resulted in different responses to the sculpturing processes of nature.

Rugged mountains in the northern part have ridges that trend north-south, at an angle to the northeasterly trend of the island. The mountains plunge into the sea, such that an indented coast with drowned valleys are common in Northern Palawan. This fjord-like coast of breathtaking beauty includes the Malampaya Sound and Bacuit Bay. Mount Capaoas (1021 meters) towers on the peninsula west of the Malampaya Sound. Bacuit Bay to the northeast of the Malampaya Sound is another area of dramatic beauty; beside it soaring peaks are capped by clouds while cliffs plunge into the cobalt sea. Some caves found in the limestone cliffs bear prehistoric remains of ancient Filipinos. The south end of Northern Palawan is deeply dissected by rushing streams. Here too is the prominent point known as Cleopatra's needle, 1593 meters high. The areas offshore northwestern Palawan have become very important to the Philippines, for these have been found to contain vast reserves of petroleum. As this is written, several oil fields that can produce 40,000 barrels of oil per day are being developed. One field, the Nido, is currently producing 14,000 barrels of oil per day after having produced about 10 million barrels of oil in 1979.

Puerto Princesa, the capital of Palawan, is in the central part where a small coastal plain is protected from the Sulu Sea by the Puerto Princesa Bay. The northwest coast of Central Palawan has cliffs pounded by relentless waves of the South China Sea. The rugged terrain in the central part of the island attains the maximum elevation in the Victoria Peak (1727 meters).

Narrow coastal plains fringe the Pantangajan Range and Pulute Range in South Palawan. The highest peak in the island, Mount Matalingajan (2054 meters), is found in the southern part. In the northwestern coast of South Palawan are numerous cliffs of limestone where caves have formed. Several of these,

such as the Tabon Cave and the Guri Cave, contain prehistoric artifacts.

In summary, the Philippines consists of islands adorned by a variety of landscapes showing the following predominant trends:

A. North-south alignment, which includes the Central Cordillera and Zambales Range of Luzon, the Central Range of Mindoro, the Central Range of Mindanao, the Diwata Range, the Western Cordillera or the Antique Range in Panay, the Range of Northern Palawan, the Cagayan Valley, Central Plain of Luzon, the Agusan-Davao Valley, the Philippine trench and the Manila trench.

B. Northeast trend, which includes the trend of Palawan Island, Eastern Negros, Western Masbate, Cebu, Zamboanga Peninsula, the Sulu Archipelago, part of the Sierra Madre Range, the Cagayan de Sulu Ridge, Palawan trough, and Tañon Strait.

C. Southwest trend, which is exemplified by the Bicol Peninsula and its alignment of volcanoes, the southern portion of the Manila Trench, Eastern Masbate, the Ticao trough, Central Range of Leyte and Leyte Valley, and the Daguma Range.

A fourth trend, mainly oriented east-west, is not as prominent as these three. However, this trend is expressed in the edge of the Catanduanes-Polilio Shelf, the north edge of Samar and the alignment of volcanoes in southwestern Luzon.

The complex topography is the product of the geologic evolution of the Philippine archipelago, which is located at the boundary of the Asian continent, the Pacific Ocean, the Sunda Shelf of Southeast Asia and the Sahul Shelf of Australia in the south. As in Palawan, Cebu and Bohol, the underlying rocks, their geometry or structure, geologic movements and the response of the rocks to climate and erosion combined to affect the end product of nature's sculpturing. The processes that formed these rocks, and the environments inferred from their occurrence, will be the subject of the succeeding chapters. This evolution of the Philippine archipelago through vast stretches of time can be deduced from the present state of the rocks underlying these islands. Their distribution and structures are represented in the geologic map shown among the plates.

The geologic map presents in two dimensions the end-product of geologic processes that have proceeded at a slow, imperceptible pace over hundreds of millions of years. A few of these processes are rapid and catastrophic, like earthquakes and volcanic activity, which often occur in islands that arc and form a garland around Asia and Australia. Like the Philippines, these islands have trenches parallel to the arcs.

Many processes, on the other hand, are imperceptible to human senses, except through direct measurement made long after they began. These are the processes that give rise to the majestic splendor of mountain chains, processes that give birth to ocean basins and lead to the growth of continents. Mountains rise and are eventually levelled while troughs are filled up. Despite the apparent permanence of the oceans, the seeming stability of the ramparts of the Montalban gorge, there is much evidence to indicate that the earth's crust is dynamic and ever changing. This is particularly true of the Philippines, which occupies a mobile zone of the earth.

Inasmuch as the temporal framework spans millions and even billions of years, it is essential to be familiar with the terms used by geologists in subdividing geologic time. The subdivisions are indicated in the geologic time table shown among the plates. The largest units are the eras, which have names derived from the nature of life as recorded in rocks. Life began to be diverse and abundant at the start of the Paleozoic (after *paleo*, Greek for old and *zoe*, life) during the Cambrian period. The pre-Cambrian eras, Archaezoic (from *archeo*, ancient) and Proterozoic (from the Greek *proteros*, former), contain only sparse and simple life forms. Because of the abundance of life in the Paleozoic and later eras, this span of time is also known as the Phanerozoic eon (from *phaneros*, Greek for visible).

The Phanerozoic consists of three eras. Rocks formed in the earliest era of the Phanerozoic, the Paleozoic, are found in the Philippines. These are mainly exposed in Mindoro, Palawan and Buruanga Peninsula, Panay Island. A Carboniferous coral was discovered in Mindoro while Permian fossils are found in Palawan, Mindoro and Panay.

Mesozoic rocks (from *mesos*, Greek for middle) are more widespread in the Philippines. These include some Triassic and

Jurassic rocks in Mindoro; probable Jurassic rocks in Panay and northwestern Luzon; and Cretaceous rocks in offshore areas of Palawan, in the provinces of Rizal and Cebu; in Caramoan Peninsula; and in other areas of the Philippines. The most extensively exposed rocks in the Philippines, however, are those belonging to the Cenozoic era (from *Kainos*, Greek for new). Included in this era are the Tertiary and Quaternary periods which are subdivided further into the epochs shown in the table. The epochs of the Tertiary may also be grouped into the Paleogene, which embraces the span of time from the Paleocene to the Oligocene, and the Neogene which stretches from the Miocene to the Pliocene. Important deposits of oil, coal and minerals are found in Tertiary rocks. The Quaternary rocks, on the other hand, contain implements of man associated with tektites determined by carbon dating to be 750,000 years old.

The events that took place in the vast period of time before man and his ancestors even appeared on earth are recorded in the rocks whose distribution is shown in the geologic map. Different rock types are shown in the map; to make the map more useful, we shall review briefly the rock types and structures shown in the map.

Rocks are generally subdivided into igneous, sedimentary and metamorphic groups. Igneous rocks (from the latin word for fire, *ignis*) include different kinds of volcanic rocks such as basalt, andesite and dacite which result from the solidification of lava pouring out of volcanoes and earth fissures. The lava is a molten mass of silicates of sodium, iron, magnesium, calcium, potassium and other elements. The different rock names reflect essential differences in the mineral and chemical composition of the rock. Basalt, for example, contains less silica, the substance used in manufacturing glass, than dacite, and andesite is intermediate between these two varieties. In the Philippines, andesite is of widespread occurrence although basalt and dacite appear in rocks of various ages. Mayon Volcano is an example of a volcano where both basalt and andesite are the products of volcanism. In some cases, volcanism results in fragmentation of the lava and the rocks around the crater or fissure. The rock thus formed is called a pyroclastic rock or tuff. The gray rock underlying Manila and surrounding cities is predominantly of

this type. In the past, it was quarried as the building stone called adobe.

The silicate melt described above may be referred to in a more general manner as magma. The magma may cool slowly at great depth to form igneous rocks called plutonic (after Pluto, the god of the underworld). Variations in composition of the magma also result in different varieties of plutonic rocks. Those rich in iron and magnesium form the rock called gabbro and related mafic and ultramafic rocks (mafic being formed from the first syllable of the element magnesium and from Fe, the chemical symbol for iron). The mafic rocks have a composition similar to that of basalt and are more abundant in ocean basins than in continental areas. These mafic and ultramafic rocks underlie the Zambales Range, Central Palawan and similar areas indicated in the geologic map. Many of these areas were formed during early Tertiary time or even earlier, during the Mesozoic. Associated with these rocks are deposits of chromite and nickel.

Other plutonic rocks are richer in silica, aluminum, sodium and potassium than the mafic and ultramafic rocks. These form the acidic or salic plutonic rocks which include diorite, quartz diorite, granodiorite and granite. These rocks usually underlie continental areas. Masses of quartz diorite, diorite and granodiorite form the core of mountain chains like the Central Cordillera of Luzon, the Central Range of Cebu and the Daguma Range. Ore deposits of gold and copper are associated with this kind of plutonic rocks.

The appearance on the surface of these rocks formed in the bosom of the earth indicates that considerable amounts of cover had been removed and that vertical movements lifted these rocks from the depths of the earth. The processes of erosion wear away rocks that are exposed and the debris is deposited as horizontal layers or *strata* in depressions, basins, troughs and in the ocean. Rocks primarily consisting of the debris of erosion comprise sedimentary rocks. These rocks may be formed from consolidated gravel and are called conglomerate. If the grains are sand, the rock is a sandstone and if finer particles are cemented, silstone, mudstone or shale is formed. The latter, shale, consists of silt and clay which also show fine layering or lamination. Many sandstones in the Philippines contain volcanic

fragments suspended in a mass of clay and silt. This impure sandstone known as *graywacke* especially common in the Lower Tertiary, and its occurrence indicate as its source an area of high relief that is being eroded rapidly, giving rise to the mixture of sand, silt and clay. The sedimentary rock may also consist primarily of chemical precipitates such as limestone (essentially calcium carbonate, the material found in seashells and coral) or chert (mainly silica, the material made into glass). These sedimentary rocks contain valuable fuel resources such as coal, natural gas and petroleum. Thick accumulations of sedimentary rock are preserved under large valleys such as the Cagayan Valley, Central Valley, Panay, Cotabato and Agusan-Davao Valley, and also in offshore areas in the Visayas, Palawan and Sulu. Limestone is soluble and large cavities develop into caves which were used as shelter by early man in the Philippines. Caves in Palawan have been valuable repositories of prehistoric artifacts.

Also found in the Philippines, especially in Cretaceous and early Tertiary rocks, are associated chert, sandstone and ultramafic rocks known as *ophiolites*. These rocks are believed to originate in ancient island arcs and trenches. Thus, it may be inferred that the Philippines had an archipelagic environment even in the past.

Pre-existing rocks may also be transformed into metamorphic rocks (from *meta*, beyond; and *morphe*, form) by processes involving high temperature and pressure. Some metamorphic rocks in the Philippines are associated with acidic plutonic bodies as a result of the heating up of the surrounding rocks during the injection of the magma into the older rocks. These metamorphic rocks do not show a distinct orientation of the grains inasmuch as heat is the main agency which transformed the rocks. Economic deposits of iron, gold, silver, copper, lead and zinc are found with this type of rock. Other metamorphic rocks like schists and gneisses show a distinct orientation of the platy and elongate minerals forming the rock. These schists and gneisses are found to be older than many other rocks in the Philippines. Schists and gneisses form under high pressures and moderate temperatures. Like plutonic rocks, their occurrence in the Philippines implies vertical movement of large magnitude. The metamorphic areas could therefore delineate zones of

mountain ranges that towered in the distant past. These are even older than the Permian rocks in northern Palawan. Some schists such as those in the island of Rapu-Rapu, off Bicol peninsula, contain deposits of base metals.

Rocks which show planar features when originally formed may be crumpled into folds whose crests form *anticlines*, and troughs, *synclines*. Some of the islands, like Cebu, are anticlinal in origin with the crest rising above the sea. The adjoining Tañon Strait, on the other hand, is synclinal with fold and deformation depressing the rocks to form a trough. Valleys such as the Cagayan Valley and Panay Central Valley are large troughs that have been filled by sediments. These troughs are outlined by the young sedimentary rocks found in the geologic map. In contrast, elder plutonic and volcanic rocks protrude as mountain ranges. Sedimentary rocks in these mountain ranges also show folding. Examples of the intricate deformation are shown in cross-sections in the plates. Cross-sections of the valleys and the troughlike structure underneath are also illustrated.

Deformation of rocks may also result in fractures along which movement may take place. These fractures are *faults*, and movement of adjoining blocks causes tectonic earthquakes. The most prominent fault in the Philippines is the Philippine fault, which extends from Luzon to Mindanao. The fault is comparable to other large faults around the Pacific basin, such as the San Andreas fault in California. The Philippine fault is indeed one of the major geologic features found on earth. Many earthquakes in recent years are associated with it. Others, however, are associated with the movement of the crust beneath the Philippine Sea or South China Sea as these crustal masses are pushed under the Philippines. Cross-sections of offshore areas across Palawan and Sulu are shown in the plates. The crust under the sea is thinner than the crust under the Philippines. A ridge is formed under the Sulu archipelago.

The record of rocks is not complete. Breaks appear when erosion removes exposed landmasses. Subsequent burial and deposition over the eroded surface result in an *unconformity*. These unconformities therefore may be used in reconstructing the ancient geography of the Philippines. They could also be used in delineating vertical movements and episodes of mountain building. Some of the major breaks in the record of rocks in

the Philippine archipelago are: (1) between Jurassic and older rocks; (2) between Cretaceous and older rocks; (3) between Upper Oligocene and Eocene rocks; (4) between Pliocene and Miocene rocks. An unconformity in middle Miocene time may be recognized in the Visayas and in the Cagayan Valley and in parts of northwestern Palawan. In northwestern Palawan, this is not as widespread as the Pliocene-Upper Miocene unconformity. The irregular distribution would be consistent with an archipelagic distribution of land and sea. Erosion would remove portions exposed along islands while deposition would take place in the straits and channels between islands.

An important part of the record of the rocks are *fossils*, which are remains of ancient life. These fossils document changes in life on earth, or evolution. They also indicate the ancient environmental conditions by comparison with present-day conditions. Corals, for example, thrive under conditions of normal salinity, clear water, warm, tropical conditions and shallow water. The occurrence of coral reefs buried thousands of feet in offshore areas in Palawan therefore implies vertical movements and conditions favorable to the development of corals. In addition to these uses, fossils may be used to correlate rocks separated by soil cover, water or great distances because some types of organisms are restricted in distribution over time. Thus, sections of oil wells drilled today may be related one to another by looking at the assemblages of fossils, especially microscopic organisms belonging to the group called foraminifera.

In igneous rocks and metamorphic rocks where there are no fossils, the ages of these rocks may be determined or approximated by measuring the amount of radioactive elements remaining. Radioactive elements commonly used for this purpose are potassium (K) which decays to Argon (Ar) and rubidium (Rb) which changes to strontium (Sr). Because of a constant rate of radioactive decay, the amount transformed and remaining is used to measure the length of time since the rock was formed. The process is similar to the growth of money in the bank by compound interest; the amount of money at one time is used to measure the length of time the deposit had been in the bank.

Even without written records, the earth scientist can reconstruct events that took place millions of years ago by looking at the rocks, their geometric relations, and the fossil content,

and by analogy with present conditions. The record of the rocks shows that the Philippines has a complex history that reaches back to hundreds of millions of years ago. The Philippines has undergone changes in geography. It has emerged from the sea many times, as it has been buried many times. It is a site where many geologic processes are active. These have endowed the Philippines with rich mineral resources. These processes remain active today; hence, volcanoes and earthquakes occur, occasionally with disastrous effect. The mineral and energy resources formed in the distant past benefit Filipinos and other peoples today, as they certainly will in the future. Moreover, the subsurface of the earth influences the shape of the surface, a fact which has important implications on politics, cultural development and government planning.

The geologic base and the history of the nation are therefore important in comprehending the past and, aided by that comprehension, in striving to shape the present and future of the Filipino people. A more detailed examination of the geologic growth of the archipelago will now be attempted in the following chapters.

Chapter Two

The Pre-Cretaceous:

THE STARS, THE EARTH AND CONTINENTAL FOUNDATIONS OF THE PHILIPPINES

Upon a limitless expanse of space through which the "soup" of primordial matter rode, the universe exploded into existence fifteen billion years ago. A respected theory, that of the "Big Bang," postulates the instant of creation as a burst of heat and light at temperatures beyond one's imagination, whose force is still felt today as light, electromagnetic waves and the galaxies continue to rush away from any given point of the universe. Through succeeding eons, the "debris" of the explosion in the form of gas and dust coalesced into disks of swirling matter. Thus began the stars and the planets. Varying densities produced varying conditions. The earth, at first with an inhospitable environment, gradually became habitable, nourishing numerous life forms that developed gradually from the first algae. From plants to primitive vertebrates to man, the imperceptible pro-

cesses of metamorphosis and growth are recorded on rocks dating back to early eons. In the Philippines are many such rocks, which testify to life's mutations and progressions in our own corner of the planet.

IN the beginning, the maker of the heaven and the earth commanded: Let there be light. And there was light.

Scientists venturing into the remote past confirm to some extent the biblical tale of the world's genesis. Fifteen billion years ago, out of that dark incomprehensible distance which was the face of the deep, time and history began with a tremendous explosion. Cosmologists call it the Big Bang. With this fierce burst of light, the chemistry and physiology of creation began. Matter and energy, locked in a primordial substance called the *ylem*, had smoldered in limitless space at temperatures reaching a trillion degrees centigrade, and at the appropriate instant, as though upon a command, exploded with infinite force to fill the universe with light.

The echo of this explosion is recorded by the 3° Kelvin cosmic background radiation and by the stretching of light and electromagnetic waves from distant galaxies and stellar objects as they rush away from our part of the universe.

Within seconds after the explosion, the temperature dropped to about a billion degrees, allowing protons to form and constitute the nucleus of the hydrogen atom. To this day, hydrogen, the first element to form, remains the most abundant element in the universe. Other light elements formed subsequently during the early stages of the universe while the temperatures were still high enough to produce fusion of nuclear particles. After three minutes, protons fused to form nuclei of deuterium, better known as heavy hydrogen because it is twice as heavy as hydrogen. Deuterium is the variety of hydrogen used in the hydrogen bomb. The process of fusion is the source of the tremendous energy released in the hydrogen bomb; it takes place at high temperatures, and its occurrence in the bomb provides only a miniature model of the process taking place in the interior of stars and our sun. When high temperatures and pressures in the beginning resulted in a fusion of protons to form deuterium, helium nuclei also formed, derived from two deuterium nuclei produced by fusion. The early products of the Big Bang are therefore hydrogen and about 22% to 28% helium. These constitute the predominant

elements of the sun and other stars. Within a few hours of the Big Bang, the temperature dropped below the point of fusion so that nucleosynthesis, the formation of elements, did not occur again until stars formed. Formation of the heavier elements, such as those found on earth today, took place during the evolution of stars. Elements heavier than iron are formed during explosions of supernovas, which are spectacular signals of the death of big stars.

Cooling and expansion of the universe continued for the first few hundred thousand years after the Big Bang. After about 700,000 years, the temperature was low enough to allow electrons to join protons and helium nuclei to form hydrogen and helium gas.

In the early stages of the universe, the temperatures were fairly high and radiation was predominant, preventing gravitational forces from binding together the gaseous matters earlier formed. Within the turbulent mass of this matter, there were random fluctuations in density. When the universe cooled further, some of the slightly denser areas in the swirling substance coalesced, and gravitational forces brought these formations together into larger units that eventually developed into galaxies.

Two billion years after the initial explosion, early stars formed and began to shed constant light upon the heavens. Some of these primeval celestial bodies were immense sources of energy, they are detected even today as quasi-stellar objects or quasars. Owing to the indescribable force of the explosion, which hurled matter in all directions, these objects are still moving rapidly away from us, so that electromagnetic waves from quasars are stretched, scientists tell us, by more than 450%. The quasars are said to be as much as 13 billion years old.

For the last 13 billion years, therefore, stars have been blazing with fire and light—"shining." Thus, by gazing at them in the heavens, we look into the past and read history, literally as written in the stars. We see stars evolving, growing old and dying in a burst of glory. To describe stars in various stages of their evolution, astronomers have used terms that evoke mythical beings—red giants, super giants, blue and white dwarfs, and black holes. From a historical point of view, the new knowledge in astronomy which reveals to us a strange and fascinating universe

may be adapted into some of the recurrent patterns in this volume—an evolution from homogeneity to diversity, a certain rhythm of disruption and coalescence, and cycles of change and renewal.

Our local star, the sun, also follows an evolutionary pattern. It was born from the ashes of another star that exploded six billion years ago. Everything in the solar system, including man, is composed of atoms that were once part of an exploding superstar. After half a billion years, the gases and dust of the former star were drawn together once more by gravity and light pressure from other stars. This contraction of the gaseous nebula formed a protosun that heated up gradually as its mass grew denser and as pressures within the increasing mass built up. Eventually, the temperatures in the interior reached the point at which the nuclei of hydrogen, helium and other elements commence to fuse. By this process a solar furnace is ignited, as it were, marking the birth of our sun as a star. Most of the energy expended on earth—to provide the driving force for biological processes, storms, wars, and revolutions, to create masterpieces of art, to grow food, to be stored as wood or fossil fuel—may be traced back to that fusion in the sun. The processes involved in the fusion, which also build up new elements, have been going on for the last five billion years and by the best estimates are expected to continue for more than two billion years.

The earth and the other planets formed from the disk of gas and dust which enveloped the protosun. The rotating mass of the protosun, now a ball of fire, dragged along with it this disk of matter and by the force of its gigantic swirl transferred to it large amounts of energy. Within the disk, itself now in swirling motion, turbulences and eddies formed. This accumulation of matter was broken up by tidal forces of the sun, as the resulting fragments subsequently were, unless they had attained certain sizes, densities and distances from the protosun. Bodies known as planetismals accreted and grew at appropriate distances from the sun. Collisions between planetismals fragmented many of them, but collisions between small ones and larger ones merely imbedded the smaller body in the larger body. By this process, planetary bodies grew and absorbed the smaller fragments in the disk.

The process of accretion is still going on today; we see it happening whenever we notice falling stars or meteorites. The process, however, was more rapid in the past, during the early stages in the life of the solar system, because then there were numerous planetismals surrounding the protosun. We still see scars of the process in the form of impact craters on the surface of the moon. Most of such scars have been erased from the surface of our more dynamic earth.

While accretion was taking place, the early sun also heated up the surrounding disk of matter, setting in motion chemical reactions and condensations of substances whose composition depended on the temperature, which itself varied according to the distance from the sun. The solar wind contributed further to variations in the composition of the substances within the disk by driving gaseous material to the outer and cooler regions of the solar system. The consequence of this is that we now find inner planets which are denser than the bigger and more massive outer planets. It also resulted in an earth whose composition and distance from the sun combine to produce conditions conducive to the development of life.

It may be said therefore that the earth, perhaps along with other planets in other galaxies still unknown to us, was destined to be the birthplace of life, with all its beauty, mystery, complexity, and occasional irrationality.

The early earth, however, was not benign and generous to life; it was a harsh environment with absolutely no air or water. Collisions heated up the planet. The decay of radioactive substances further increased the temperature of the early earth, in time bringing it to a point intense enough to melt iron sulfides and eventually metallic iron and nickel. These heavier substances settled into the core, which to this day contains molten iron and nickel. Convection currents within the molten core produced the earth's magnetic field, another life-sustaining force in the planet because it shields living creatures against lethal radiation from space.

The formation of the core caused widespread volcanic activity which drove relatively lighter rocks to the surface to form the crust. Water, carbon dioxide, methane, nitrogen and other gases

were also products of this intense volcanic upheaval. These gases formed the oceans and earth's atmosphere.

The earth then was uninhabitable. The air was without oxygen, filled instead with suffocating and noxious gases. The temperature on the surface was extremely high, not unlike that of the present surface of Venus. In time, however, the air was cleared of much of the carbon dioxide; chemical reactions with calcium in rocks formed calcium carbonate, the material that constitutes seashells. The formation of calcium carbonate also helped to decrease the acidity of the early oceans. The removal of carbon dioxide from the early atmosphere permitted heat to escape and the earth's surface to cool down.

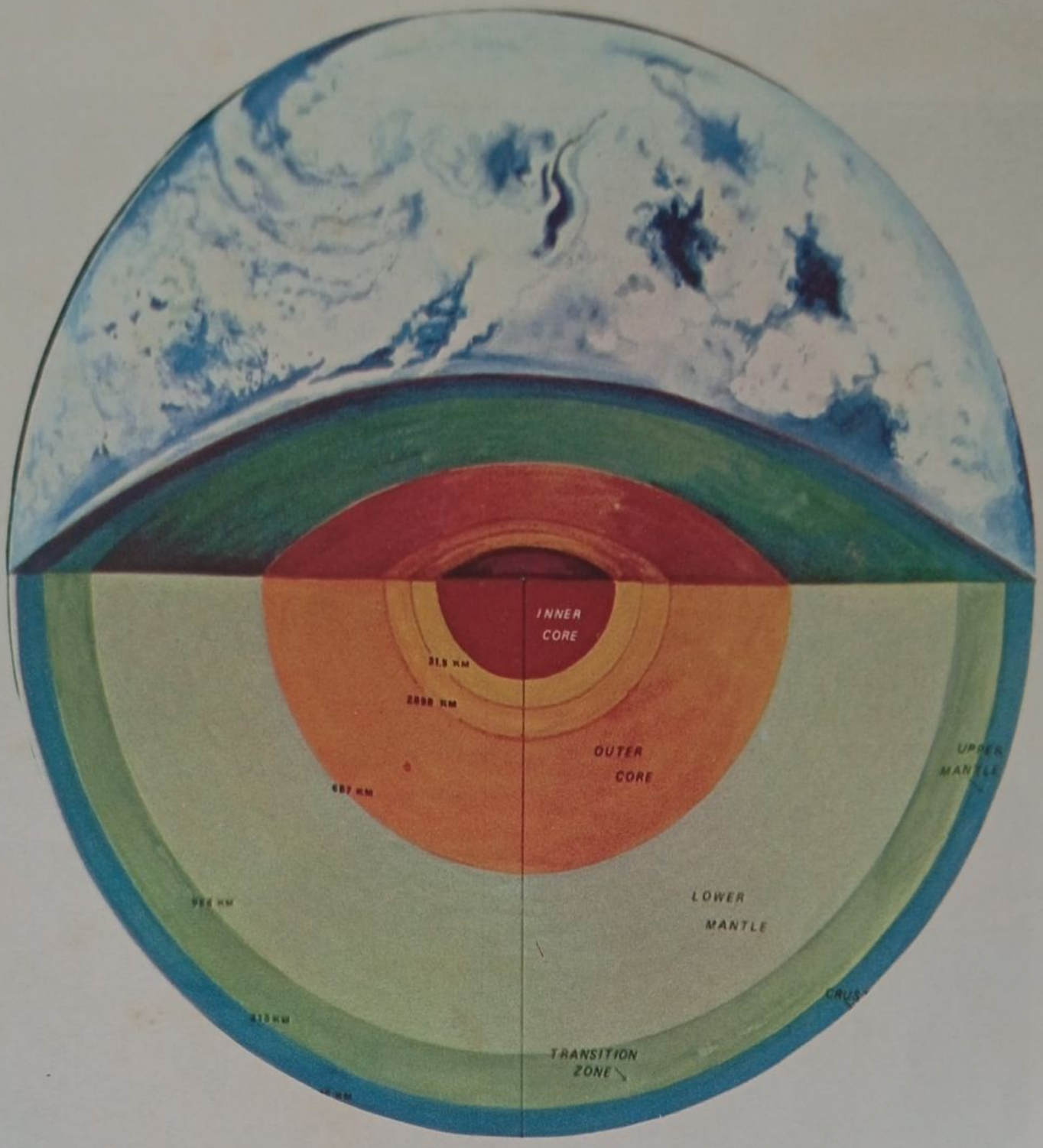
The building blocks of life formed as lightning and ultraviolet radiation passed through the atmosphere, which then contained methane and ammonia. These accumulated in the early oceans and formed an organic soup from which life developed. Half a billion years after the begining of the earth 4-1/2 billion years ago, the conditions here on earth became suitable to the emergence and development of life.

The earliest signs of life consisted of single-celled organisms similar to bacteria. Remains of these organisms are observed in the Fig Tree rock formation found in Barberton, South Africa, which has been dated rediometrically to be 3.1 billion years old. The algae and bacterium-like structures in the rock are accompanied by hydrocarbons, suggesting that the organisms were already photosynthetic. Additional evidence of photosynthesis in some of the early organisms comes from structures in a limestone from Bulawayo, Rhodesia. This limestone, dated as 2.7 billion years old, contains structures similar to those produced by blue-green algae, the slimy organism found in coral reefs.

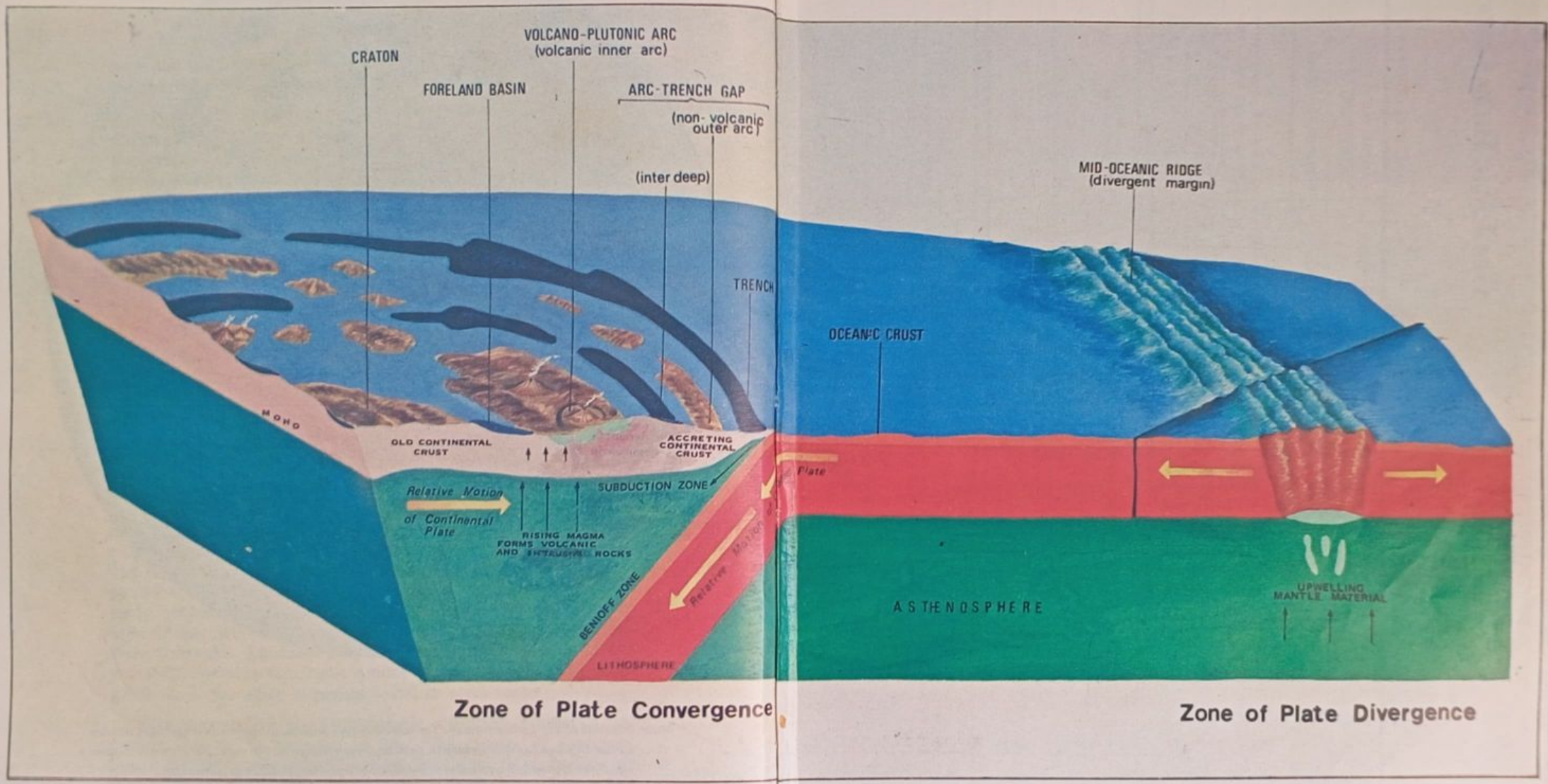
The development of photosynthetic organisms marks an important step in the evolution of life. The process of photosynthesis enables plants to utilize sunlight in the manufacture of food from nutrients in the environment. Oxygen is a by-product of the process. We therefore owe the food we eat and the air we breathe to the miracle in the evolutionary process that took place over three billion years ago.

The first few billion years of the earth's history are included in the Precambrian, the span of time preceding the Cambrian

#3084



Major Divisions of the Earth's Interior. The mantle (green) predominantly of iron-magnesium silicates similar to those found in ultramafic terranes in the Philippines. The outer core (orange) consists mainly of molten iron and nickel while the inner core (red) is solid iron and nickel.



Zone of Plate Convergence

Zone of Plate Divergence

Cross section across the Lithosphere and Asthenosphere showing features developed in the convergent and divergent zones of continental and oceanic plates. The Philippines is situated along a zone of convergence. The oceanic crust which is denser than the crust underlying continents is formed along diverging plates marked by mid-oceanic ridges. A trench is formed by the collision of the oceanic plate with the continental plate. Earthquakes and volcanism characterize the zone of collision.

RELATIVE DURATIONS OF GEOLOGIC ERAS

Geologic Time Chart

	PERIOD		EPOCH	DATE	BIOLOGICAL FEATURES
CAINOZOIC	Quaternary		Pleistocene	10,000 to 2 million	First true man: Homo erectus
	Tertiary	NEOGENE	Pliocene	2 to 10 million	First man-like apes
			Miocene	10 to 25 million	
		PALEOGENE	Oligocene	25 to 40 million	First monkeys and apes
			Eocene	40 to 60 million	
			Palaeocene	60 to 70 million	First primates: prosimians
MESOZOIC	Cretaceous			70 to 135 million	First flowering plants Last dinosaurs
	Jurassic			135 to 180 million	First birds
	Triassic			180 to 225 million	First mammals First dinosaurs
PALAEOZOIC	Permian			225 to 270 million	
	Carboniferous			270 to 350 million	First coniferous trees First reptiles First insects
	Devonian			350 to 400 million	First forests First amphibians First bony fish
	Silurian			400 to 440 million	First land plants
	Ordovician			440 to 500 million	First vertebrates: Armoured fish without jaws
	Cambrian			500 to 600 million	Invertebrate fossils: First shell-bearing animals
PRECAMBRIAN				600 to 4,500 + million	First living things: Algae, bacteria

Physiographic Map of the Philippines

GEOLOGIC AND MINERAL DISTRIBUTION MAP OF THE PHILIPPINES

RAL DISTRIBUTION MAP OF THE PHILIPPINES

Compiled and drawn by the Geological Survey Division
Bureau of Mines
1973

EXPLANATION

SEDIMENTARY AND METAMORPHIC ROCKS

QUATERNARY

CENOZOIC UNDIFFERENTIATED

TERTIARY

MESOZOIC - TERTIARY

MESOZOIC

PALEOZOIC - MESOZOIC

PALEOZOIC

PRECAMBRIAN - PALEOZOIC

IGNEOUS ROCKS

Intrusive and Hypabyssal Rocks

Acid Intrusives
γ_4 - Post Mesozoic (N, Pgl)
γ_3 - Mesozoic (PJ)

Basic and Ultrabasic Intrusives
δ_3 - Mesozoic

Effusives

Cenozoic Volcanics

Volcanics older than Cenozoic

Geological data not available

ctive and semi-active volcanoes, extinct volcanoes

Important Faults:
a) established
b) conjectural

Geological Boundaries:
a) established
b) conjectural

MINERALS OTHER THAN MINERAL FUELS
METAL ORES

Iron and Ferro-alloy Metals:
Cr, Ni
Cr, Fe, Ni
Cr, Fe, Mn, Ni

Base Metals:
Cu
Cu, Hg, Pb, Zn,
Cu, Hg

Precious Metals:
Au
Au
Au

Workable deposits with non-indicated or unknown reserves

Workable placer deposit

Occurrences

Operating and Abandoned Mines (For grade I and II only)

Ore District

INDUSTRIAL MINERALS AND ROCKS
Ceramic and Refractory Minerals:
Cly, Do, Fl, Mgs
Cly, Do, Fl, Si
Cly, Do, Fl, Mgs, Si

Chemical and Fertilizer Minerals:
S
Ba, Gy, Py, S
Gy, P, Py, S

Other Industrial Minerals:
Dl, Ls
Asb, Ls
Asp, Btn, Ls, Tc

Workable deposits with non-indicated or unknown reserves

Workable placer deposits

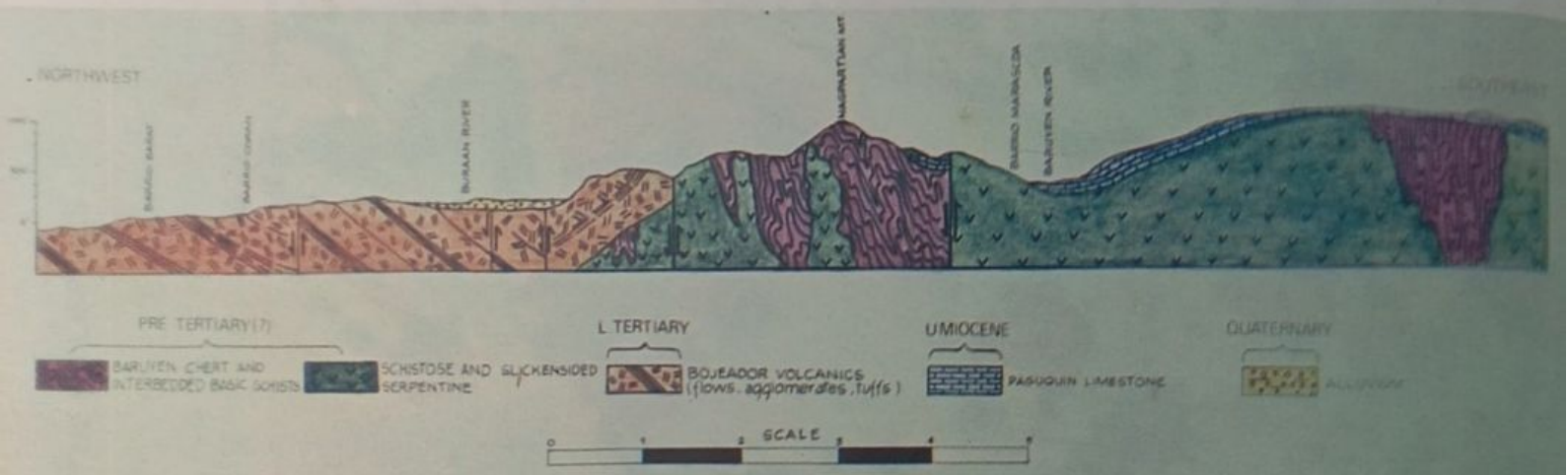
Occurrences

Operating and Abandoned Mines (For grade I and II only)

MINERAL FUEL

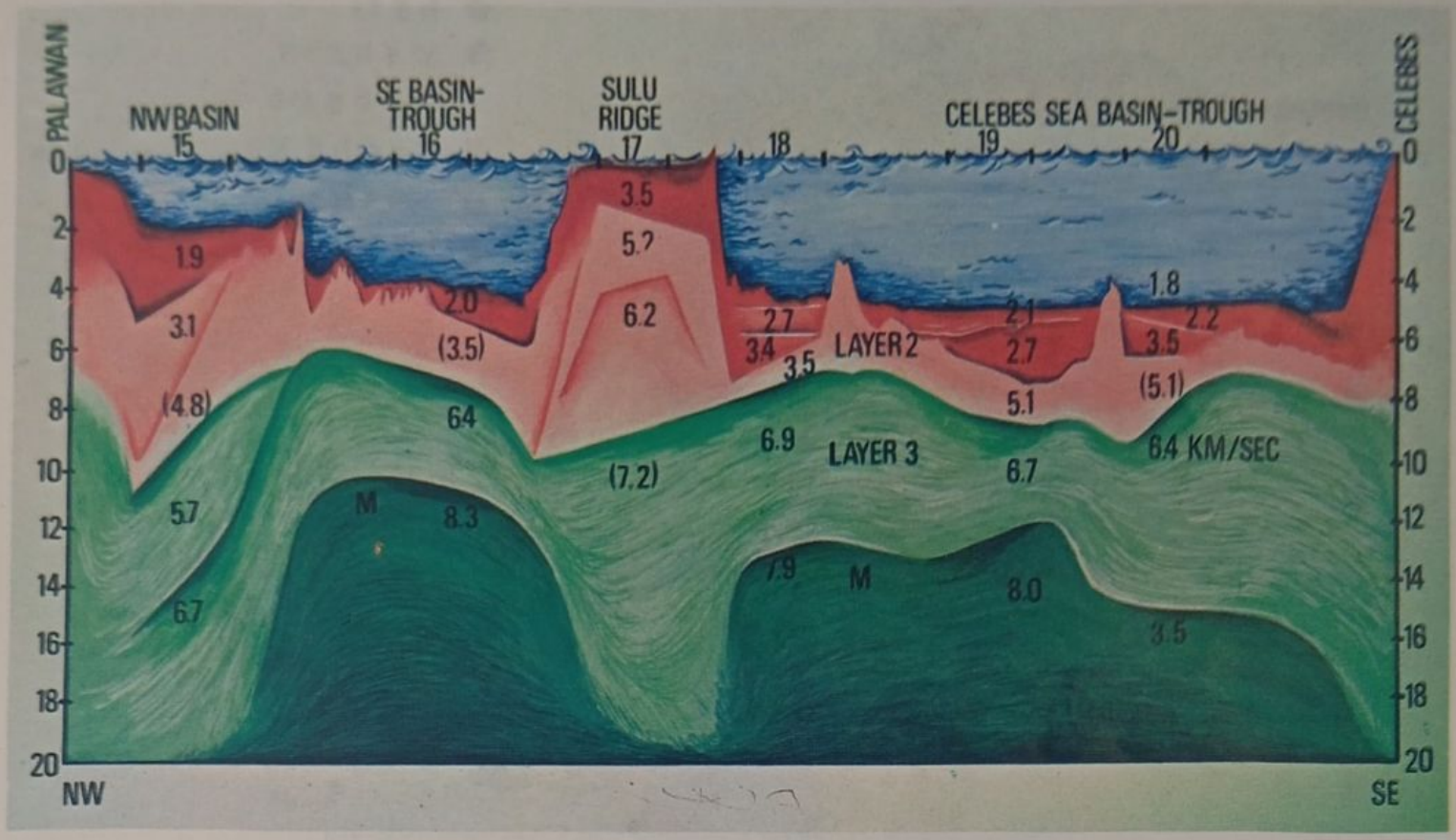
Coal
Bituminous
C_2 Workable with unknown or non-indicated reserve

LUZON
POLILLO I
CATANDUANES
MARINDUQUE
MASBATE
SAMAR
PANAY
LEYTE
CEBU
NEGROS
BOHOL
PALAWAN
MINDANAO
S U L U S E A



RECENT
MIO-PLIOCENE
EOCENE

VOLCANIC
INTRA. & META. B.C.



ABOVE LEFT:

Geologic section through Baruyen River Area, Ilocos Norte. The long and complex history of Northwestern Luzon is recorded in rocks that have been deposited since pre-tertiary times. Several cycles of deformation, uplift, erosion and subsidence produced the complex geometry of the rocks in the area. The discordant boundary betweeen pre-Tertiary rocks and Lower Tertiary rocks indicate during Early Tertiary times. Gaps in deposition are also found between Upper Miocene and Pre-Tertiary rocks and between Quaternary and Lower Tertiary rocks.

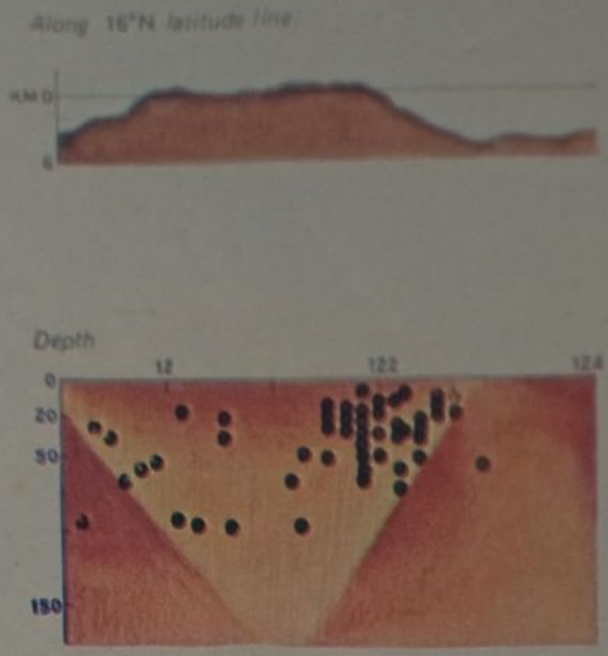
BELOW LEFT:

Geologic cross section across Mindanao through the Agusan, Davao and Cotabato Basins. Thick sedimants fill Tertiary basins while igneous and metamorphic rocks underlie mountain ranges. Young volcanic rocks (red) cover Bukidnon plateau.

ABOVE:

Cross section of the crust and mantle of Palawan, Sulu and Celebes. Northwest Sulu basin has a thicker cover of sediments with velocities of 1.9 to 2.0 Km/sec. than the southeast side of the basin. The crust thickens under Palawan. Subdivisions of the crust and mantle are based on the velocities of transmission of seismic waves in Km/sec. Denser rocks of the mantle have higher velocities while crustal rocks and unconsolidated sediments are characterized by low velocities.

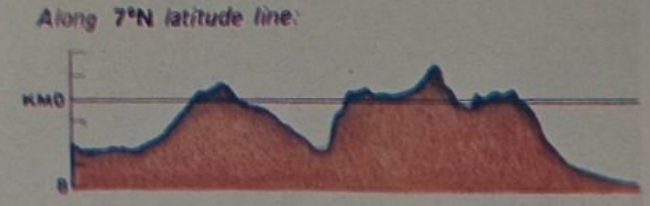
118
120
122
124
126
128° E
h ≤ 33
33 < h ≤ 70
70 < h ≤ 150
150 < h ≤ 300
300 < h ≤ 450
h > 450
18
16
14
12
10
8
6
18° N
16
14
12
10
8
6
118
120
122
124
126
128

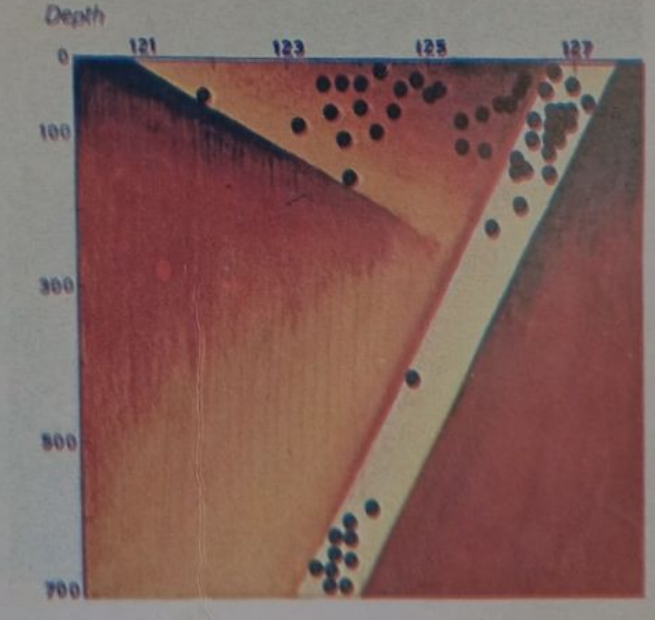


LEFT:

Map showing the distribution of earthquake activity in the Philippine Archipelago. A high concentration of earthquakes may be correlated with the Philippine Trench, Manila Trench and the Philippine fault.

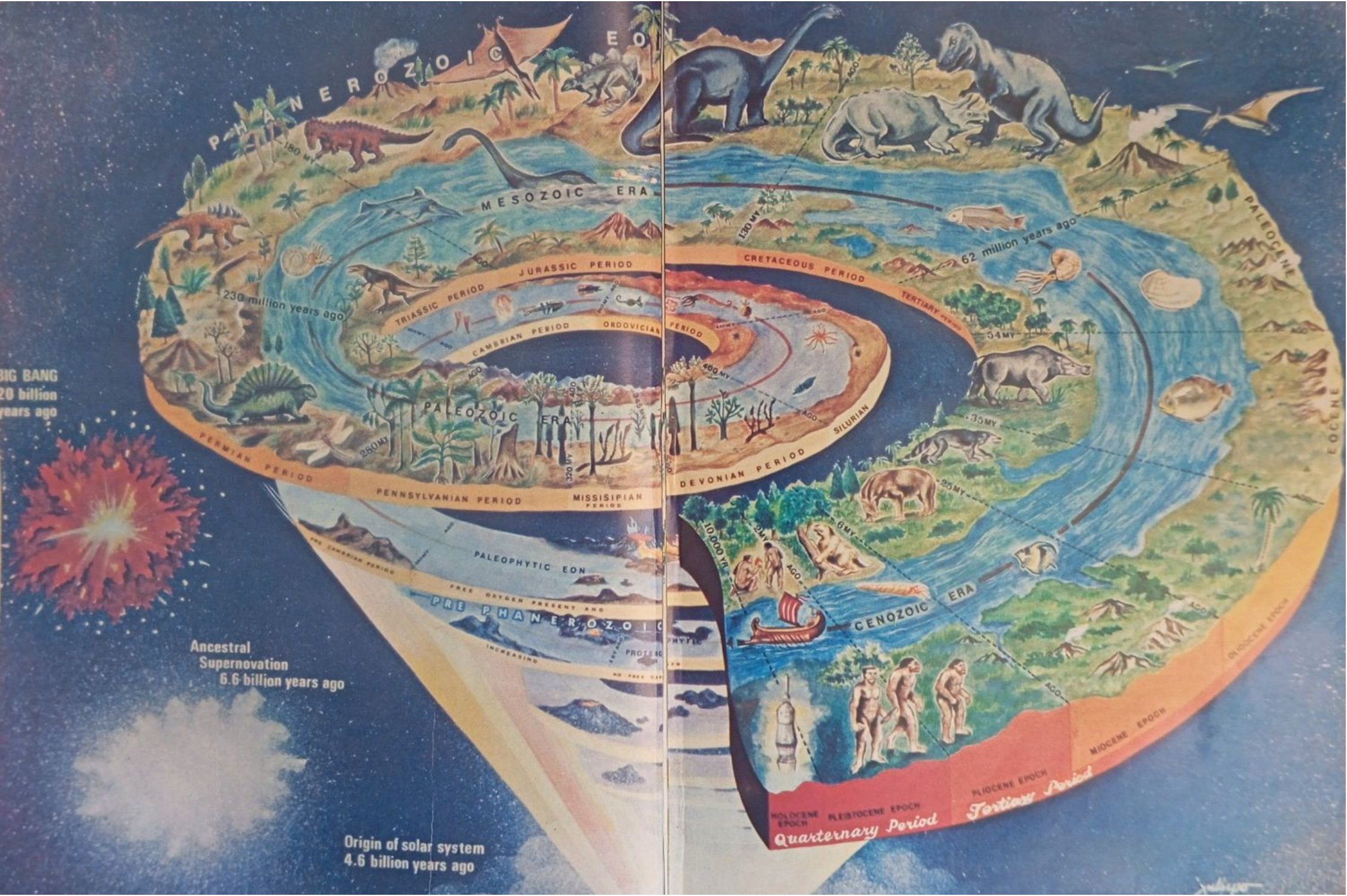
The symbols refer to depth (h) of earthquake foci in kilometers.

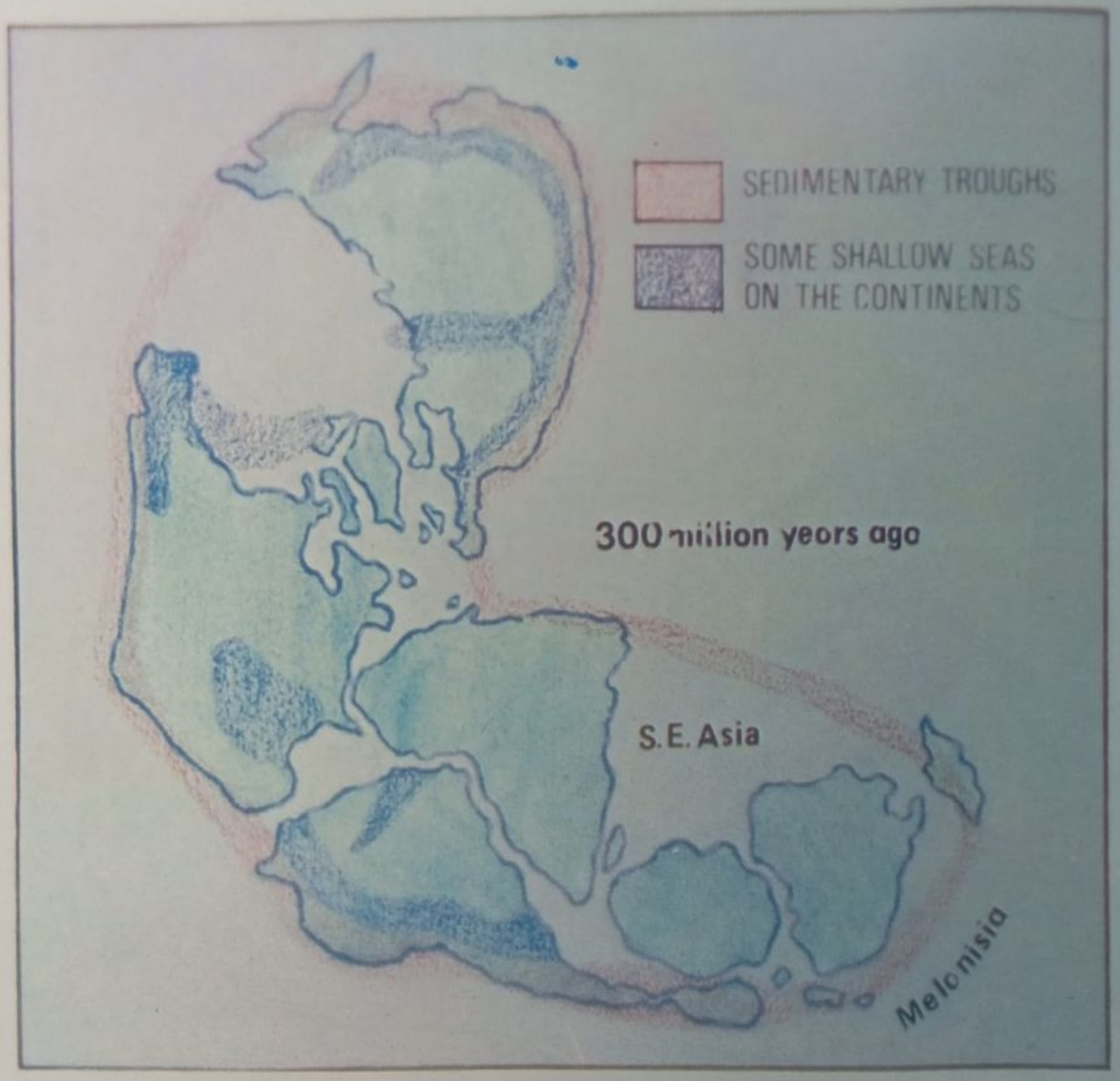




RIGHT:

Cross sections across the Philippines along 7^{o} N and 16^{o} N latitudes showing distribution of earthquake centers of activity. The upper part of the diagram shows the outline of the earth's surface. The dots indicate the positions of earthquakes.


PHANEROZOIC EON
MESOZOIC ERA
180 MY AGO
230 million years ago
TRIASSIC PERIOD
JURASSIC PERIOD
CRETACEOUS PERIOD
130 MY AGO
62 million years ago
TERTIARY PERIOD
PALEOCENE
EOCENE
34MY
35MY
25MY
CAMBRIAN PERIOD
ORDOVICIAN PERIOD
SILURIAN PERIOD
DEVONIAN PERIOD
PALEOZOIC ERA
600 MY AGO
500 MY AGO
400 MY AGO
320 MY AGO
280 MY
PERMIAN PERIOD
PENNSYLVANIAN PERIOD
MISSISIPIAN PERIOD
PALEOPHYTIC EON
PRE CAMBRIAN PERIOD
FREE OXYGEN PRESENT AND INCREASING
PRE PHANEROZOIC
PROTEROZOIC
ARCHEOZOIC
NO FREE OXYGEN
CENOZOIC ERA
10,000 YR AGO
1MY AGO
6MY AGO
60 MY AGO
HOLOCENE EPOCH
PLEISTOCENE EPOCH
Quarternary Period
PLIOCENE EPOCH
Tertiary Period
MIOCENE EPOCH
OLIGOCENE EPOCH
BIG BANG
20 billion
years ago
Ancestral
Supernovation
6.6 billion years ago
Origin of solar system
4.6 billion years ago



ABOVE:

Reconstruction of the continents 300 million years ago as proposed by Tarling and Tarling.

RIGHT:

Reconstruction of Gondwanaland showing the position of SE Asia as proposed by M. Ridd (1971). Various lines of evidence suggest that the positions of the continents in the past were different from their present positions. Movement of continental masses are related to plate motions shown in an earlier illustration. Gondwanaland is an ancient supercontinent consisting mainly of Africa, South America, India, Australia.

KHASI HILLS
Shan Scarp
Song Ma fold & fault belt
Thailand
INDO-CHINA
TALCHIR
INDIA
Kalong Maru fault
AUSTRALIA
Malaya
Sumatra
Borneo
CEYLON
Java
90
85
80
75
25
20
15
10
100
15
10
5
80
105
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115
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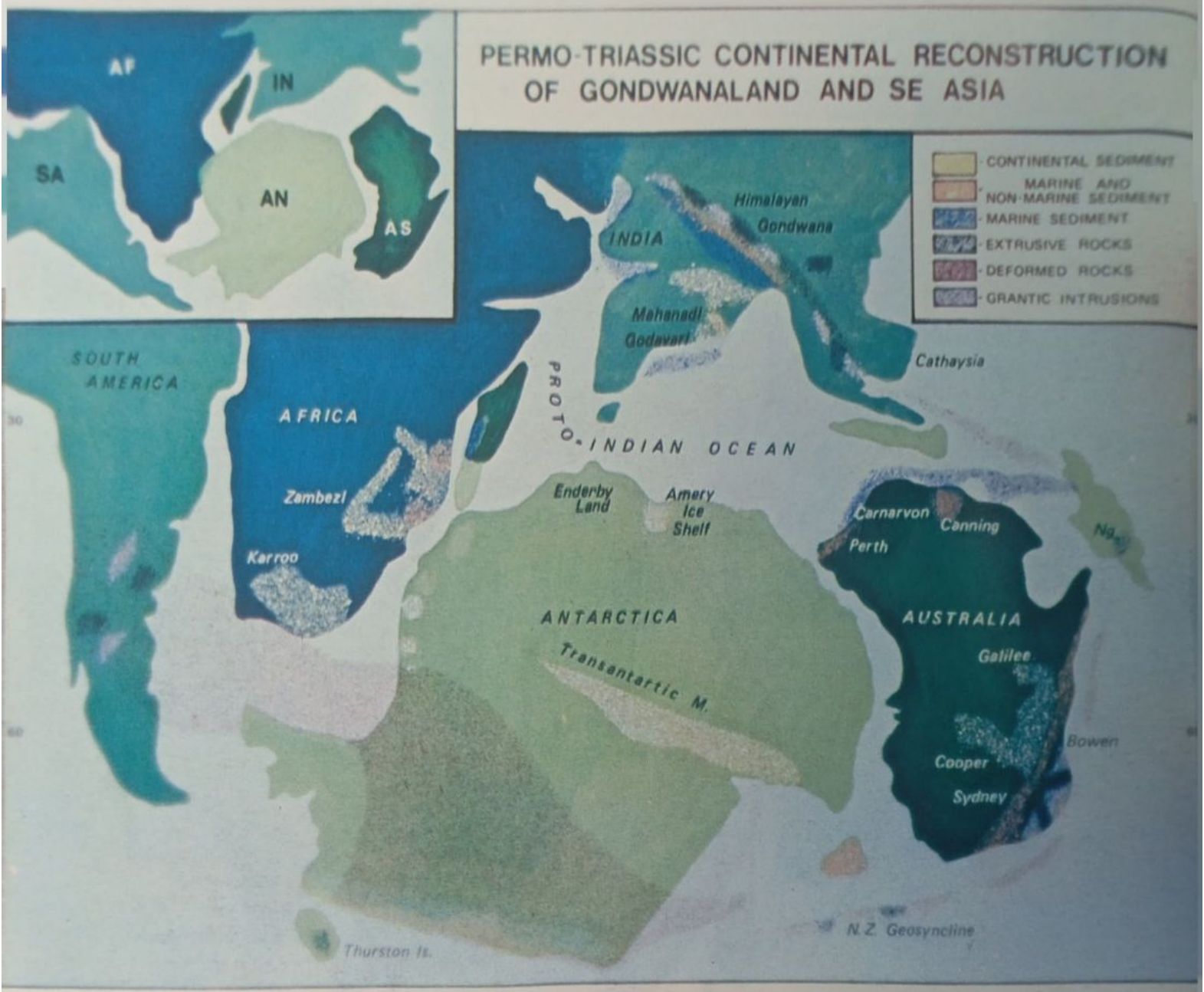
125
30
25
20
15

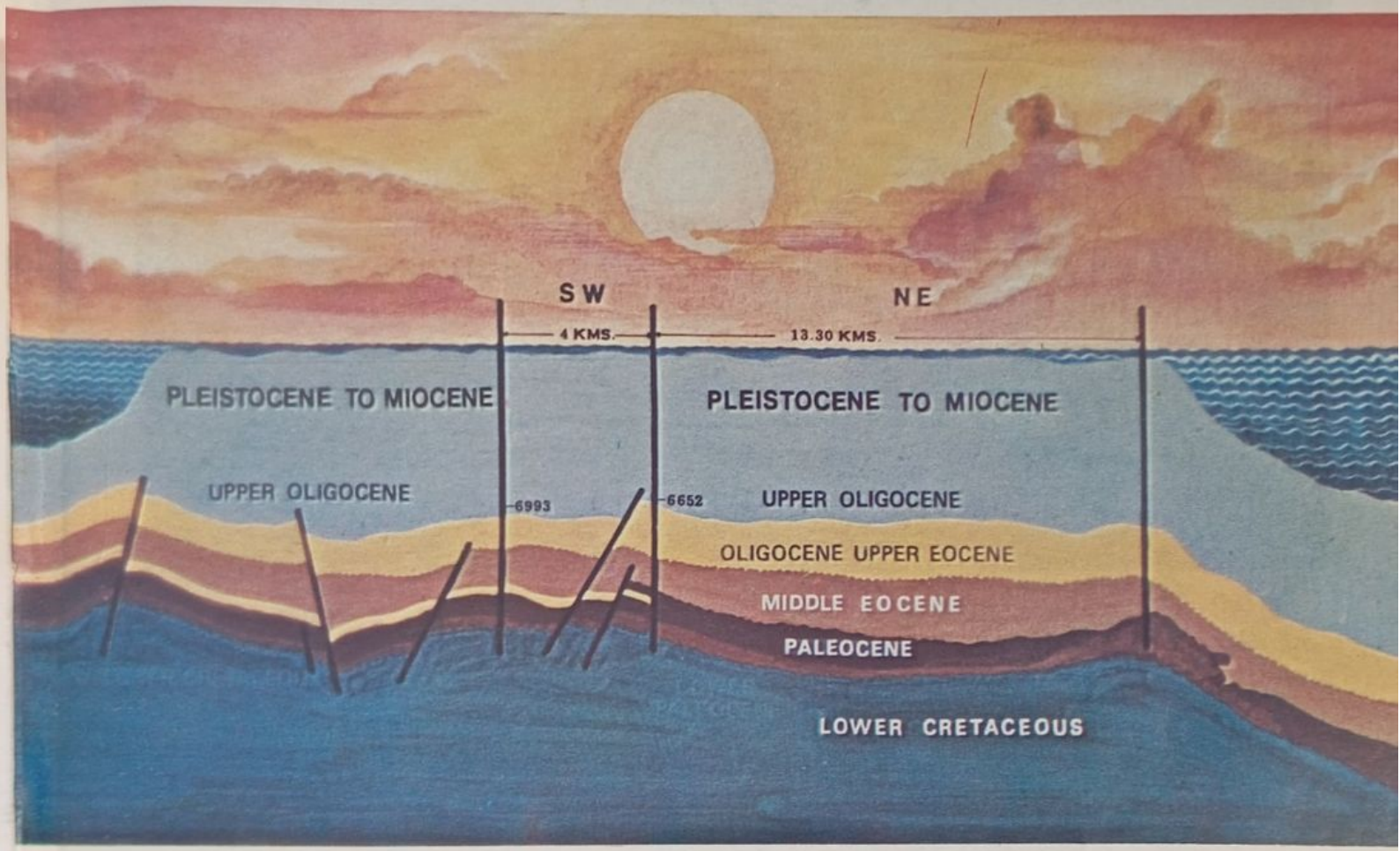


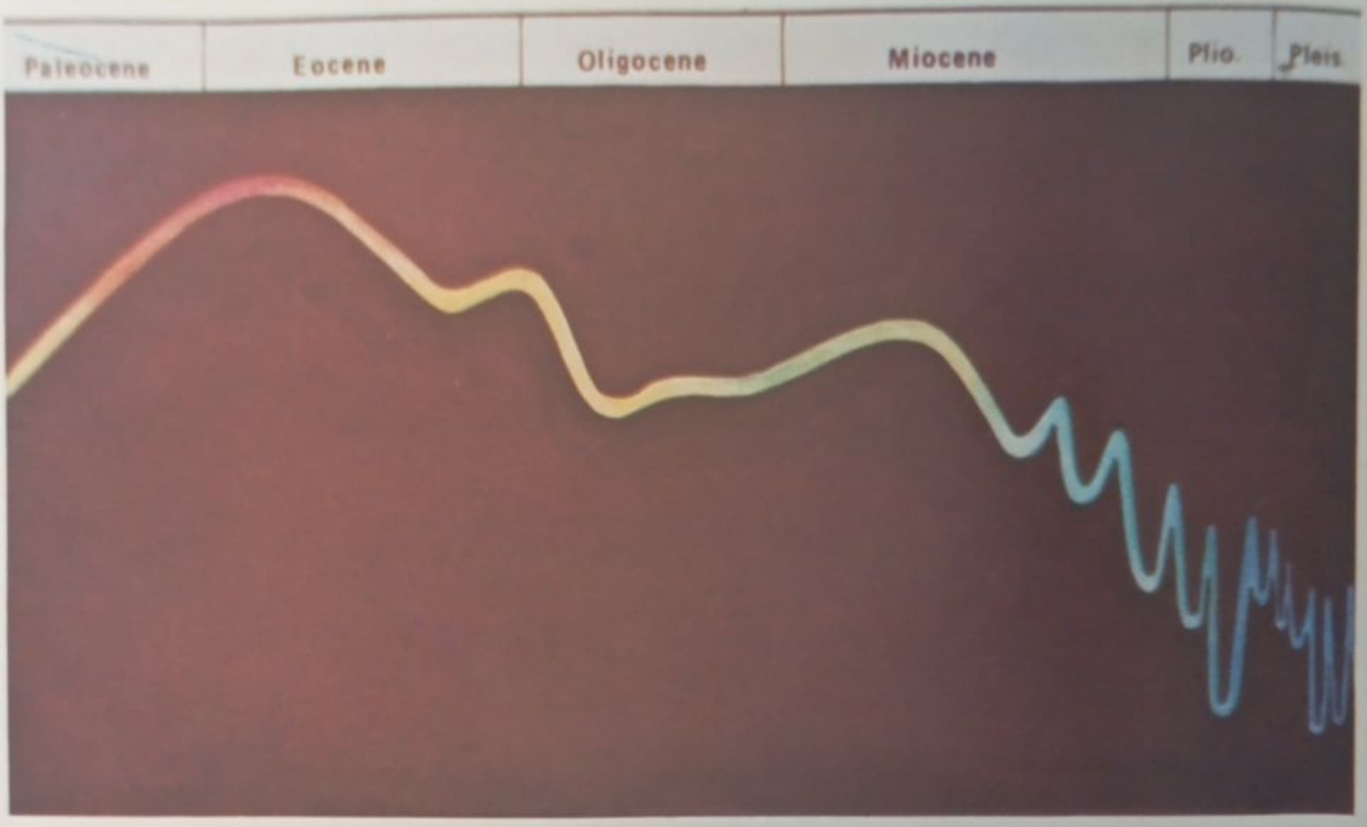
ABOVE:

Permo-Triassic continental reconstruction of Gondwanaland and Southeast Asia. This is another version of the arrangement of Gondwanaland and Southeast Asia.

RIGHT:

Cross section of the Recto Bank showing its development from Mesozoic times to the present. The present day reefal complex is built on deformed Cretaceous to Oligocene rocks. Data from oil exploration show that these ancient rocks are similar to rocks found under NW Palawan.


SW
NE
4 KMS.
13.30 KMS.
PLEISTOCENE TO MIOCENE
PLEISTOCENE TO MIOCENE
UPPER OLIGOCENE
6993
6652
UPPER OLIGOCENE
OLIGOCENE UPPER EOCENE
MIDDLE EOCENE
PALEOCENE
LOWER CRETACEOUS



ABOVE:

Variation of the average temperature during the Cenozoic. The average temperature declined during the Early Oligocene. The Quaternary is characterized by large and numerous fluctuations of temperature which accompanied glaciation.

period which began about 600 million years ago. Most of the remains of life in the Precambrian consist of simple plants and bacterium-like organisms. The most abundant record of animal remains from this eon is preserved in sandstone in the Ediacara hills, 450 kilometers north of Adelaide, Australia. These rocks cointain impressions of jellyfish, corals, worms and forms which have not been classified. The rocks were deposited in the latter part of the late Precambrian, a period between 1,400 and 600 million years ago. During this time two episodes of glaciation are recorded in the Late Precambrian rocks of Australia.

As we attempt to unravel early stages of evolution on earth, we find that only a few traces of simple life forms exist today and this is because organisms with hard parts were not yet developed at the time. There was not enough oxygen in the atmosphere to sustain more complex organisms. Only metazoa with low oxygen requirements could survive in an atmosphere which probably contained only 3% of the present oxygen level.

Precambrian rocks have not been demonstrated to occur in the Philippines. In addition to the occurrences in South Africa and Australia already mentioned, Precambrian rocks form the core of continental masses. These are stable units known as *shields* and found in China, India, Siberia, Scandinavia, North America, Brazil and Antarctica. Surrounding the shields are mountain chains or remains of mountain chains that have since been leveled by erosion through the millions of years of geologic time. The processes of erosion, along with other geologic processes, have changed the face of the earth. The distribution of land and sea has shifted; mountains rise and are leveled, basins and troughs are filled; continents grow and are fragmented. As a consequence, climates change and these changes may lead to widespread extinction of organisms if these are not sufficiently adaptable to new conditions.

Fortunately conditions have thus far continued to be favorable to life even to the diversification of life forms. Remains have been found of more complex organisms that lived within a few million years of the start of the Paleozoic era which began 600 million years ago. Included among them are echinoderms related to our present-day sea urchin, sponges, corals, worms, brachiopods related to the *balay* (Lingula) which we still find in Manila Bay today. The early sea did not contain fishes but it

swarmed with trilobites, an arthropod, the group to which our crabs today belong. Snails were already present, and towards the end of the Cambrian, a relative of the modern-day nautilus makes its appearance. In analogy to present-day conditions, the Cambrian seas must have been warm and conducive to the abundance and diversification of life.

The complexity of life forms in the Cambrian is in marked contrast to the scarcity and simplicity of Precambrian organisms. This suggests that in the transition from the earlier to the later period there was sufficient accumulation of oxygen in the atmosphere to support the more complex life forms. Other evidence, such as the composition and volume of sedimentary rocks, isotopes and trace elements indicate that since the start of the Paleozoic, the composition and volume of the oceans have been fairly constant. Thus after almost four million years, the earth was transformed from a harsh uninhabitable planet to one which would set the stage for the dramatic dance of life which eventually leads to man, a unique organism with the capacity to look into the past across billions of years and to preserve knowledge for future generations but at the same time has the weird ability to destroy the environment that took those billions of years to evolve.

The earth, though already more hospitable to life during the early Paleozoic, would nevertheless in its condition at the time appear to us a strange planet. The land would be barren; there are no trees, flowering plants or even grasses. The early Cambrian seas contain no fishes, only some primitive corals, jellyfish, sponges, brachiopods and arthropods. The latter, represented by an extinct group called trilobites, become predominant during the Cambrian.

The favorable environment, however, was conducive to the diversity of life. In the succeeding period, the Ordovician, the seas were also populated by colonies, formed like branches, of now extinct graptolites associated with other marine invertebrates such as bryozoa, brachiopods and nautiloids. The first vertebrates, the ancestor of all organisms with a backbone, including man, also appeared during the Ordovician.

Evolving through a period of 160 million years, marine life became more varied, so much so that during the Silurian the seas teemed with echnoderms, gastropods, pelycypods and brachio-

pods. In the Silurian seas flourished eurypterids, extinct arthropods resembling lobsters with the features of a scorpion. These were predators that sometimes grew to more than three meters long. The closest relative of the eurypterids among the arthropods is the horseshoe crab *(Limulus)*, which is common in the Pacific from Japan to Sumatra. This marine arachnoid first appeared in the Triassic. The early vertebrates therefore had to protect themselves by developing bony scales to serve as an armor. These were the early fishes, which like the modern lamprey, had no jaws.

The first land plants also appeared in the Silurian. These were primitive lower vascular plants, similar to some that we still see in certain marshes today. By Devonian time, which began 400 million years ago, some primitive ferns have appeared. Fishes become more abundant during this period. The jawless fishes decline as the jawed fishes become established. Some fishes, like the *Dinichthys*, become giants, growing to more than nine meters long. The fearsome sharks, still common in Philippine waters, are a primitive group of fishes that first appeared during the Devonian. In Northwestern Malaysia and Southern Thailand, upper Devonian to lower Carboniferous red beds contain small brachiopods, trilobites, ostracods, gastropods and crinoids.

Some parts of the Devonian world experienced periods of aridity. In pools, ponds and streams that dried up, survival favored animals that could withstand the loss of water. The ability to travel between pools also guaranteed survival. This ability may be observed even today in some Philippine fishes, such as the *martiniko* and *hito* (catfish). The *dalag* (mudfish) can also survive in mud with very little water. The pressures of an arid environment led to the development of amphibians during the Devonian. Later, during the Carboniferous, reptiles evolved from an amphibian ancestor.

The remains of the oldest insect, consisting of wing fragments, come from the lower Pennsylvanian in Czechkoslovakia, Germany and Pennsylvania, U.S.A. From this may be inferred that insects are the first animals on earth to conquer the air. They must have appeared earlier than the Pennsylvanian; but during the Carboniferous, the forests provided an environment favorable to their rapid evolution, so that during the Permian,

19 orders of insects are known. Metamorphosis, the transformation of a caterpillar into a butterfly, is a characteristic developed by insects in the Permian. This trait, plus the ability to flex the wings and fly completes the three important characteristics developed by insects during the Late Paleozoic. Since then, no further important evolutionary step has been taken in the development of insects. Thus, dragon flies and cockroaches have characteristics that have been unchanged for more than 250 million years. Like man, insects have been able to adapt to varying environments. Some, like the ants and the bees, have developed highly organized societies. Although many are considered harmful or bothersome, insects are essential to the reproduction of many plants which depend on them to transmit pollen from flower to flower.

Lower Paleozoic rocks have not yet been definitely established in the Philippines. Upper Cambrian rocks are found in the Malayan peninsula. Cambro-Ordovician rocks have also been found in Northern Thailand. Sedimentation in the Malayan peninsula continued up to the Devonian. Rocks of this period are present in Borneo.

The oldest rocks in the Philippines are regionally metamorphosed rocks (schists and some gneisses) unconformably overlain by Permian to Jurassic rocks in Mindoro, Northern Palawan, Northwestern Panay and Romblon. In the eastern coast of the Philippines, from Catanduanes, the Caramoan Peninsula, Larap, Camarines Norte, Tayabas, Polilio, up to Nueva Ecija, Nueva Vizcaya and Isabela, schists are unconformably overlain by Cretaceous rocks. These metamorphic rocks are found in Surigao, Cotabato and, more extensively, in Zamboanga. Pre-Cretaceous schists are also found in Cebu and Bohol.

Although these metamorphic rocks have not yet been dated radiometrically, their occurrence indicates a cycle of sedimentation and, in some places, volcanism, before the periods from the Permian to the Cretaceous.

Burial and heat, combined with stresses, transformed these pre-existing rocks into metamorphic rocks. This process takes place during orogenesis, or mountain-building events. The distribution of the basement metamorphic rocks in the Philippines may therefore be taken as markers indicating the sites of ancient

mountain ranges formed millions of years ago and since worn down by long periods of erosion by streams and other agents. Wataru Hashimoto and Tadashi Sato, in 1968, deduced an episode of metamorphism, completed before the Middle Jurassic, which left rocks in Mindoro on a northeast-southwest trend. In Northern Palawan, the same authors discerned a pre-Middle Jurassic metamorphism which influenced rocks older than Middle Permian. In the Tayabas Isthmus, Toshio Kimura *et al.* noted in 1968 that the foliation or orientation of platy minerals in rocks of the Pre-Cretaceous basement have an eastwest trend. These trends record the direction of past stresses which deformed the rocks. They may also correspond to the alignment of ancient mountain ranges in the Philippines.

Granites, whose emplacement is related to the cycle of mountain-building, have been dated in neighboring areas. Early Carboniferous granite is found in Northern Thailand. Permian to Triassic granites were emplaced in the Malay Peninsula. The granite in Belitung was emplaced during the Middle to Late Triassic. In Taiwan, the Tananao schists contain Permian fusulinids and corals. In Northern Palawan, weak metamorphism is observed in the Middle Permian to Triassic rocks of the Malampaya Sound group. These conditions are traces left of considerable geologic turbulence in the Southeast Asian region during the transition from the Paleozoic to the Mesozoic.

The oldest remains of life in the Philippines date back to the Carboniferous. The fossil that constitutes these remains is a coral assigned to the genus *Gshelia*, although it strongly resembles corals belonging to the genus *Caninia*. The specimen comes from a limestone cobble in a Late Tertiary conglomerate in Mindoro. The presence of the coral suggests that some of the basement rocks in the Philippines are at least as old as the Carboniferous. Furthermore, it shows that the climate then was warm and that the sea was shallow, with normal salinity.

Carbo-Permian rocks are also found in Borneo. In the Sudong valley, Fusulinids and *Calamites* sp. (possibly *Calamites leioderma*) were used to obtain a dating of the rocks. The *calamites* is a tall, reed-like plant related to the horsetails. It was very common in the Carboniferous, the period during which much of the coal in Europe was deposited. As already indicated, Permian fossils have been recovered from rocks in Northern Palawan,

Romblon and Mindoro. The rocks identified include fusulinids, conodonts and algae.

The presence of Permian rocks in the Philippines was definitely established with the discovery of *Neoschwagerina* and *Paraschwagerina* in limestone from Carabao Island, Romblon and of *Schwagerina* and *Verbeekina* from a pre-Eocene conglomerate exposed in the Sipatag River, Mindoro. These fossils show a widespread distribution with the general *Neoschwagerina* and *Paraschwagerina* having been found in Sumatra, Japan, China, Afghanistan, Sicily and the United States. These are marine protists that live in open, shallow, offshore waters of normal salinity and moderate temperature.

Additional fusulinids from the Eocene Agbahag conglomerate are: *Pseudofusulina fusiformis* (Schellwien) *P. kraffti* (Schellwien), *Schwagerina hawkinsiformis* Igo, *Misellina ibukiensis* Kobayashi, *M. claudiae* (Deprat), *Pseudoliolina sp., Cancellina* sp., *Neoschwagerina cf simplex Ozawa, Schubertella giraudi* (Deprat), *Yangchienia compressa* (Ozawa), *Rauserella?* sp., *Minojapanella* sp. and *Nagatoella* sp. Associated with the fusulinids are Permian calcareous algae. The following were identified by R. Endo: *Pynoporidium dilatatum* Endo, n. sp. *Paleophyllum hashimotoi* Endo, n. gen. and sp. *Archaeolithoporella hidensis* Endo, *Gymnocodium japonicum Konishi, Vermiporella nipponica* Endo, *Macroporella* sp., *Physoporella cf. konishii* Endo and *Pseudoepimastopora japnica* Endo. The presence of algae also indicates shallow marine waters.

In Northern Palawan, along Malampaya Sound, Minilog Island and the Manmegmeg Bay coast, conodonts and fusulinids are found in Permian rocks along with algae, crinoid stems and gastopods. In Minilog Island, black limestone contains *Verbeekina* cfr. *verbeeki* (Geinitz), *Parafusulina* sp., *Maklaya* sp. and *Neoschwagerina* sp. Conglomerates in the Manmegmeg Bay coast contain the following conodont fauna: *Gondolella rosenkrantzi, Spathognathodus* sp., *Ozarkodina tortilis, Neospathodus* sp. and *Hindeodella* sp.

Conodonts are tiny, paired, toothlike remains consisting of calcium phosphate. Their zoological affinities and function are not definitely known. In the southern tip of South Gunto Island, also in Northern Palawan, the following conodonts indicating

Middle Triassic age were found: *?Prioniodelia prionidellides ?Neohindeodella uniforma, Ozarkodina tortilis.* Traces of radiolaria are found in chert located in the same formation where these conodonts occur. In contrast with the fusulinid-bearing limestone of the Permian, the Middle Triassic rocks indicate deeper marine waters.

During the Triassic, land plants prospered in Southeast Sarawak; 87% of these flora belonged to the *Sphenopsida* and *Pteropsida,* which are also found in North Vietnam. The others were *Neocalamites carrerei, Annulariopsis* and *Equisetum.* There are no members of Gingkopsida and Coniferopsida. The plants lived in sandy, damp environments similar to our present-day swamps and marshes. *Equisetum,* commonly known as horsetail, has persisted to this day in the Philippines.

During most of the Mesozoic (up to early Cretaceous time), the principal land plants were ferns, conifers, gingkoes and cycads. The last two types, the most dominant during that age, are still found in the Philippines. The cycad is a common ornamental plant (see plate) used in landscaping today.

Abundant Triassic fossils are found in Timor where almost 100 species have been described. Included in this rich yield are pelecypods, ammonoids, nautiloids, gastropods, brachiopods, hydroza, crinoid stems, worn tubes and plant remains. Extremely slow deposition is indicated in shallow waters far from lands supplying sediments. Dark limestones also suggest stagnant conditions.

In many other parts of the world, the Triassic shows a marked difference in living organisms compared with the preceding periods of the Paleozoic, hence the name Mesozoic for the era which starts in the Triassic. Reptiles start becoming dominant. Many Paleozoic organisms become extinct. The first mammals appear in the Upper Triassic record, evolving from mammal-like reptiles that first appeared during the Permian and became extinct during Triassic time.

Reptiles became larger during the Jurassic and the Cretaceous. Giant dinosaurs, the largest vertebrates that ever lived on land, flourished during this time. The plant-eating *Brontosaurus* measured more than 24 meters from the tip of its nose

to its tail. This giant reptile spent its time in swamps and rivers, far from giant carnivores like the *Tyrannosaurus*.

All environments were conquered by the reptiles in the Mesozoic. Aquatic reptiles first appeared during the Permian but by the Triassic, icthyosaurs that looked like modern sharks and porpoises had already adapted to the marine environment. In the Late Triassic, long-necked plesiosaurs, described as snakes attached to the body of a turtle, grew to 15 or more meters in length and fed on fishes that inhabited the Mesozoic sea. Other giant reptiles, such as the mosasaur, lived during the Cretaceous. This proliferation of giant creatures must surely have filled the land and seas with the sounds of combat as they strived endlessly to demonstrate the first principle of life, the survival of the fittest.

Reptiles took to the air in the Jurassic. Pterosaurs also attained formidable measurements, the *Pterandon* having a wingspan of almost 10 meters. Birds evolved from a reptilian ancestor. The *Archaeopterys* found in Upper Jurassic limestone in Silesia had both avian and reptilian features.

Reptiles today comprise lizards, snakes, turtles, and crocodiles, the last two of which first appeared in the Triassic. Turtles occupy a place of honor in the animal kingdom; they have survied to this day without much change in their basic structure. Crocodiles were among the animals that attained formidable size in the Mesozoic. One specimen from the Upper Cretaceous, found in Texas, had a skull measuring almost two meters long. Like the crocodiles we find in the Philippines today, the Mesozoic crocodiles lived in tropical to subtropical swamps and rivers.

No dinosaur remains have yet been found in the Philippines, but there are Jurassic rocks in Mindoro and their base suggests that these rocks were deposited in a pre-Jurassic erosional surface or land. In the upper course of Kipalaya River, ammonite rich black shale is interbedded with carbonaceous sandstone. This rock contains *Cladophlebis*-like plant impressions. Furthermore, in Sumagui, Bongabong, Oriental Mindoro, *Cyathocaulis yabei* Ogura, n. sp. was collected from a float. This tree-fern ranges from the Upper Jurassic to Upper Cretaceous in Japan. This suggests that land in the Philippines during the Mesozoic contained fern forests.

The Mansalay area in Mindoro has yielded a rich collection of marine Jurassic fauna containing more than twenty-five genera of ammonites, nine genera of bivalves and belemnites. Ammonites are related to the present-day *Nautilus*; belemnites are related to squids and octopi. Ammonites found in Mindoro include *Oppelia fusca* Queentedt, *Peltoferas arduennemse* d'Orbigny var. *mindorensis* de Villa, *Streblites, Phylloceras* and *Lytoceras*. The last two genera commonly inhabit waters ranging from 80 to 100 fathoms deep, the infrabathyal zone.

Bivalves are associated with the ammonites. *Pecten* and *Chlamys* (Radulopecten?) *villai* Kobayashi n. sp. are found with them; the former is the beautifully symmetrical clam which we find in today's seas and whose picture is a symbol of one of the oil companies. Among the bivalves from the Mansalay area are *Vaugonia* (Vaugonia) *mindorensis* (Hayasaka) *Astarte* (Astarte) *mindorensis* Hayami n. sp., *Myophorella* (*Promyophorella*) *orientalis* Kobayashi and Tamura, and *Inoceramus* sp. cf. I. *galoi* Boehm. The last two indicate that Mindoro belonged to a Western Pacific province which included Japan and Indonesia. This faunal province is consistent with other assemblages, such as ammonities. Its constituent organisms are in marked contrast to the Indo-African province which included Ethiopia, the Himalayas and Somalia. A nektonic bivalve, *Aulocomyella*, similar to the species A. *neogeae* Imlay found in Mexico, is found with the other bivalves.

Other rock formations in the Philippines contain radiolarian remains described by W.D. Smith in 1913 as Jurassic *Cenosphaera affinis* Hinde and *Dictyomitra tenuis* Hinde.

Drilling in offshore Palawan and the Recto Bank unearthed precious information on the plant life of ancient Philippines which could be used to elucidate past geographic relationships between the Philippines and other areas. The plants that yielded this new information are noted here as being similar to the flora of Australia and India. Further support is therefore given to the suggestion by M.F. Ridd in 1971 that Southeast Asia was part of the supercontinent known as Gondwana. These assumptions are also consistent with findings on ancient magnetism of rocks which could record the past position of an area with respect to the magnetic north and south poles. The results

of paleomagnetism of Philippine rocks, discussed further in Chapter 6, indicate that the polar wandering curves indicated for the Philippines, India and Australia follow similar patterns in contrast with other areas of the world.

The floral unity in Palawan and the Recto Bank gives additional evidence of the intimate connection between these places, which is also indicated by geology, the sequence of rocks and by evidence from geophysics (seismic methods). Hence, the shelf area of the Philippines extending to the Recto Bank is not just the result of an accident of morphology. On the contrary, even as far back as the Mesozoic, 200 million years ago, the Recto Bank was obviously an integral part of Palawan. Remains of land plants during the Mesozoic and breaks in the records of rocks known technically as unconformities clearly show that the land area of the Philippines included this shelf area west of Palawan. The complex geological history of Palawan and the Recto Bank, parallel in such details as the advance and retreat of the seas and in rock types, persists into the Tertiary. Deeper penetration into the basement that forms the foundation of the Mesozoic sequence will probably yield evidence of unity of these areas extending further back into the Paleozoic. Continuity of basement rocks may be traced in seismic sections stretching from Palawan to the Recto Bank. In offshore areas, Permian foraminifera known as fusulinids are reworked into Mesozoic sedimentary rocks. The fusulinids are neoschwagerinids, namely *Pseudodoliolina* sp. and *Verbeekina* sp. *Pseudodoliolina* is also in Oriental Mindoro, while *Verbeekina* sp. occurs in Carabao Is., Panay.

More knowledge of ancient flora and of the sequence of rocks has been derived from several offshore wells. In the western part of Palawan, Cadlao 1 in the northwestern part and Peñascosa 1, west of Central Palawan, are deep wells whose cuttings and drill cores have been studied for pollen. In the Recto Bank, wells A-1 and B-1 have also yielded a rich variety of pollen.

Several species of *Classopollis* dominate the flora of southwestern Philippines during the Jurassic to Early Cretaceous. Classopollis classoides is identified in Cadlao, Peñascosa, and the Recto Bank. The pollen genus *Classopollis* is believed to comprise pollen derived from an extinct gymnosperm, perhaps *Cheiro-*

lepsis or *Brachyphyllum*. The gymnosperms are represented in the Philippines today by such plants as pines and cycads. *Classopollis* is therefore a conifer whose habitat consists of coastal areas with dry climatic conditions. This genus was dominant in the southern hemisphere during Late Jurassic times.

In Palawan and the Recto Bank, *Classopollis* is associated with *Zonalpollenites dampieri, Podocarpidites* sp. *Eucommiadites* sp. and several species of *Araucaricites, Cyathidites* and *Gleichenidites. Araucariacites australis* is identified in the Recto Bank, and Peñascosa. *Araucaria,* erect and majestic, is cultivated today in the Philippines as an ornamental tree. *Cyathea* is a tree fern also inhabiting Philippine forests today. A trunk of the *Cyathea*-type *Cyathocaulis yabei* was found by Ogura in 1941 in Bongabong, Oriental Mindoro. *Cyathidites* minor and *Cyathidites australis* are found in wells A-1 and B-1 while species of *Cyathidites* are found in Cadlao 1. The long-ranging spores of *Leiotriletes* are abundant in A-1 and B-1 in the Lower Cretaceous section while in Cadlao, species of this spore genus is found in the Jurassic to Lower Cretaceous portion. *Lycopodiacidites austroclavidites* and *Alisporites* sp. are found in Cadlao. The latter species was also found in Peñascosa; one report identified the species as *Alisporites thomasii. Cicatricosisporites dorogensis* is common in Peñascosa. This species is also present in the Recto Bank. It is identified in Cadlao with other species (*Cicatricosisporites* cf. *autralis, C.* cf. *geopperti, minor*) also found in the Recto Bank. *Piceapollenites* sp. is present in Cadlao and the Recto Bank. The presence of *Gingkocycadophytus nitidus* shows that plants belonging to the gingko group were present in the Philippines during the Mesozoic. In Peñascosa, *Exesipollenites tumulus, Aequitriradites* sp., *Cicatricosporites australiensis, Appendicisporites tricornitatus* are associated with *Classopollis classoides.*

The assemblage just mentioned resembles the *Exesipollenites* assemblage of the *Classopollis-Microflora* of Western Australia as reviewed by Basil E. Balme in 1964. In Western Australia, *Classopollis* is also associated with *Zonalpollenites dampieri, Araucariacites australis, cyathidites, Gleicheniidites,* and members of the families *Schizeaceae, Matoniaceae* and *Osmundaceae.* Comparable flora are also found in Ceylon and India. *Classopollis, Cyathidites* and a form resembling *Zonalpollenites dampieri* is described in

Jurassic microflora in West Punjab by S. C. D. Sah in 1955. Western Australian forms with *Zonalpollenites dampieri* and *Araucariacites australis* are found in the Upper Jurassic and Lower Cretaceous sedimentary rocks of India. *Classopollis, Araucariacites* and *Zonalpollenites*, based on the work of Bolkovitina in 1956, are noted by Balme (op. cit.) as not being major elements in the Jurassic of Russia. Although Balme recognizes similarities between Australian and European flora of the Upper Jurassic, he considers an important difference in the apparent restriction of "trisaccate, podocarpaceous pollen grains to the Southern hemisphere and the Indian subcontinent." *Leiotriletes* in the Philippines down to the Upper Jurassic have species in rocks as old as the Devonian in Australia. *Laevigatosporites* in the Permian of Australia are included in the description of Balme cited.

An important change in the flora of Europe and Australia took place in late Jurassic times. *Cicatricosisporites dorogensis* and the closely similar *C. australiensis* appear. *C. dorogensis*, found in the Philippines, is also found in India, Hunan, the Soviet Union, Western Canada, Maryland and Delaware. The wide distribution of the ferns during the Mesozoic led Balme in 1964 to suggest that humid conditions were widespread and that extensive climatic barriers did not exist. Conditions favorable to migration of ferns could also have accompanied the mountain-building movements that marked the beginning of the Cretaceous.

There was therefore abundant life in the Philippines in the Jurassic and this included land plants, and numerous molluscs. During that time, climatological conditions on earth were equable and uniform, as may be inferred from the widespread distribution of dinosaurs, coal, evaporites and phosphate deposits. Warm climates covered a wider area than today. There were no ice caps and the air temperature decreased 22° C from the tropics to the polar regions, less than the variance of about 40° C today. The Philippines belonged to the Indo-Pacific region, which included New Zealand, Australia, Indonesia and Japan.

The sparse but widespread distribution of basement metamorphic rocks throughout the Philippine archipelago suggests that the early life of the Philippines may have passed through a continental stage during the Paleozoic. This continental area would include Taiwan, Indochina, Malaysia and Indonesia. From

the Permian to the Triassic, mountain building resulted in upheavals known as the Indonesian orogeny.

A possible reconstruction of Southeast Asia is presented by Ridd in 1972. He bases this reconstruction on various lines of evidence. The succession of sedimentary rocks in Thailand points to a land source to the west. The rocks also contain rare fragments of the plants *Glossopteris* cf. *angustifolia* and *Palaeovittare parvifolia* which are elements of the Gondwanaland flora. The reconstruction takes into consideration geological structures, such as faults, and also the continental edge as defined by the depth of 1000 meters below sea level. The reconstruction is not satisfactory because Australia overlaps a large area of Borneo.

An alternative reconstruction is given by Don and Maureen Tarling in their 1977 edition of a book on Continental Drift. Three hundred million years ago, Southeast Asia, Australia, Antarctica, India, Africa and South America formed the supercontinent known as Gondwana. This closely, resembles the reconstruction of Gondwana in the Permo-Triassic times as proposed by S. K. Acharyya in 1978. These reconstructions are all consistent with the suggestion that the early Philippines was contiguous to Australia and India. The similarity in the Jurassic flora of Palawan to those of Australia and India suggests that the connection between these areas may have persisted up to Middle Mesozoic times. Paleomagnetic data from the Tertiary of the Philippines also support the close relationship between the Philippines, Australia and India.

Fragmentation of Gondwanaland and separation of the fragments eventually brought the continents to their present positions. Ancient magnetism of rocks points to a location south of the equator as the original position of Gondwanaland.

There are still many problems connected with the unraveling of the early history of the Philippines. For instance, the widespread distribution of basement metamorphics may be the result of an ancient landmass that was eroded and subsequently covered. The other possibility is that this landmass was broken up by succeeding earth movements. The latter is more consistent with recent plate tectonic models concerning the evolution of East and Southeast Asia, but further studies would have to be made to achieve a better degree of certainty about the Philippine genesis.

Although the ancient rocks are not as rich in earth resources as the younger rocks in the Philippines, we still derive benefits from marble formed millions of years ago. Barite and salt deposits are found in the Jurassic rocks of Mindoro. The Mansalay formation is also rich in organic material which, under favorable circumstances, could be converted to petroleum. It is therefore a potential source rock for the generation of much needed hydrocarbons. Stratiform and massive sulfide deposits are found in metamorphic rocks of Mindoro, Rapu-Rapu, Albay and Isabela, all of which also have the potential of containing gold deposits. The occurrence of continental-type material is also favorable to a concentration of radioactive elements, such as uranium and thorium.

The Jurassic marks the end of the earliest history of the Philippines as recorded in rocks. This pre-Cretaceous time spanned 4.4 billion years from the beginning of the earth. The record, of course, is imperfect to this day. Like ancient histories written on missing, faded or damaged pages, it has many gaps that all the more sharpen the curiosity and leave the mystery of the remote past all the more tantalizing.

Chapter Three

The Cretaceous-Paleogene:
EMERGENCE OF OUR ISLAND WORLD

The Philippines began as an archipelago through a period of 100 million years partly during the Cretaceous and partly during the Paleogene epochs. It was a period of great upheavals, both in the structure of the earth and in life itself on the planet. The world's flowering plants originated in this period, many of them appearing for the first time in Southeast Asia. The reptiles that dominated earth life in the Mesozoic soon began to disappear as the Cretaceous ended, about 70 million years ago, and in their place, from epoch to epoch gradually came new forms of animals, this time types with increasing intelligence to cope with the problem of nourishment and the demands of survival. Traces of this dramatic evolution from the earlier primates, man's ancestors, are found in some areas on the Western Pacific, in rocks which suggest that at the time this huge ocean already existed. In the

Philippines, rocks of the Cretaceous and Paleogene epochs are widespread, containing fossils of the early forms of life that thrived in the tropical climate. Studies of these rocks have been both exciting and profitable, yielding a geologic history marked by volcanism, mountain building, and plate movements, as well as less convulsive developments. These geologic events, besides influencing various life forms, developed certain earth resources from which contemporary man is deriving incalculable benefits.

A PERIOD spanning about a hundred million years between the Cretaceous and the Paleogene embraces the earliest beginnings of the Philippines as an archipelago. Great changes in life occur within this period, during which man's earliest primate ancestors appear. The land and seas that support life in the archipelago went through gradual and sometimes abrupt, wrenching transformation that itself influenced the forms and modes of life.

One of the major changes in life is that of the appearance of angiosperms, the flowering plants, which happens during the Early Cretaceous. They soon became predominant, replacing the gingkoes and cycads which then reigned supreme in Mesozoic forests. Many of the world's primitive flowering plants first found life in Southeast Asian forests, raising the probability that the earliest flowering plants may have originated from this region.

Reptiles that ruled earth during the Mesozoic period—dragonlike dinosaurs and the flying pterodactyls—still flourished in the Cretaceous period but they mysteriously began to disappear towards the end of this period, with the process beginning perhaps during the Mesozoic era. Several explanations have been suggested, such as unfavorable climatic changes accompanying the upheavals that created mountains during the end of the Mesozoic era, epidemics, and even the development of mammals that acquired a taste for dinosaur eggs. We may never know the exact causes of their extinction, which set in after the height of their development was reached in the late Jurassic age. After roaming the earth as a dominant species for a hundred million years, the great reptiles disappeared, leaving behind only a few pale facsimiles of themselves today.

With the extinction of the behemoth reptiles in the Cretaceous period, the stage was set for the explosive revolutionary radiation of mammals in the Cenozoic age, our age. Before this, only the remains of small mammals were found in Mesozoic rocks. These early mammals were about the size of present-day rodents and the arrangement of their teeth suggests that they subsisted mostly on plants. During the Cretaceous period, insect-eating mammals appeared and if the deduction stated earlier is right, they were dinosaur-egg eaters also. Marsupials, as well as placentals, grew in numbers toward the end of the Cretaceous age.

From the insectivores or insect-eating mammals, the carnivores or flesh-eating mammals developed. This development is reflected in the shape and arrangement of the teeth. Unlike plant-eaters whose food remained fixed and therefore easy to reach, the carnivores developed greater intelligence and agility in order to catch their prey. The ancestors of the wolves and dogs are traced back to the late Eocene age. The ancestors of cats came later, during the Oligocene age.

Many other domestic animals which now serve man or provide food for man evolved during this period of geologic history. The ancestor of the horse first appeared in the Eocene age. Camels developed in the late Eocene. Elephants have ancestors dating back to the early Oligocene period. Pigs descended from Asiatic pigs which appeared in that same period.

The earliest primates were about the size of a squirrel. This species lived in Paleocene forests. By the time of the Eocene period, primates similar and related to the tarsiers of the Philippines were already well developed and adapted to living in trees. These were man's ancestors.

The Western Pacific faunal province noted in the previous chapter suggests that the Pacific ocean existed prior to the period covered here. Organisms that lived from the Cretaceous to the Eocene ages are found in guyots or submerged flat-topped seamounts, between the Marshall and Hawaiian Islands. Cretaceous corals, a group of clams known as rudistid lamellibranchs, Paleocene and Eocene pelagic foraminifera are reported by E. L. Hamilton in 1953 to have existed in these guyots. In the Eniwetok Atoll, Tertiary sedimentary rocks dating back to the Eocene age overlie a type of volcanic rock called olivine basalt.

Eocene rocks are also found in Guam and on the islands of Micronesia. In Spain and Rota, various marine organisms were reported by Shoshiro Hanzawa in 1957 to occur with foraminifera. Among these were echinoid tests and spines, bryozoa, corals (*Saipania tayamai Yabe* and Sugiyama in Saipan), molluscs and algae. The latter include the genera *Corallina, Lithophyllum, Lithoporella, Halimeda* and *Archaeolithotamnium.* These algae have also been found in Eocene rocks of the Philippines.

The lithology and biota of the Eocene limestones in Micronesia indicate tropical waters. The limestones were deposited in lagoons and reefs similar to the coral reefs we see today. These environments intergrade towards moderately deeper waters, especially where there are abundant foraminifera similar to recent *Globigerina* ooze. Like conditions prevailed in the Philippines where we find similar fossils and rocks. As we shall see later, however, there are also differences in other areas of the Philippines, which was already archipelagic during that time.

In the Philippines, marine organisms comprise most of the traces of life that existed during this period. Warm climate prevailed. In some areas by the sea, swamps with plant life became the source of coaly sediments and coal fields such as those found in the Eocene of Catanduanes. The sea surrounding the Philippines at that time provided a medium whereby cosmopolitan species could travel. Thus, the presence of some of the fossils found in many parts of the world, in Asia, Africa and Europe.

Cretaceous to Paleogene rocks are widespread in the Philippne archipelago. The geologic map shows that these rocks can be found as far north as Ilocos Norte and Davao in the South, and that they are present in areas from Samar in the East to Palawan in the West.

Most of the living organisms described from the start of the period called the Cretaceous consist of remains of the protozoan group called foraminifera. These fossils are found in Eastern Rizal, Quezon, Camarines Sur, Catanduanes, Samar, Cebu and Palawan. The genus *Globotruncana* is found in these localities, except for Palawan where the genus *Gumbelina* is reported to occur. *Orbitolina* occurs in Cebu and Catanduanes. In addition to foraminifera, algae are found in the Cretaceous rocks of Caramoan, Camarines Sur. In the Tayabas Isthmus, Quezon, the fol-

lowing species were found in a sheared zone within Miocene rocks: *Globotruncana fornicata* Plummer, *G. concavata* Brotzen, *G. lapparenti bulloides* Vogler, *Biglobigerinella multispina* Lalicker, *Panomalina Caseyi* Bolli, Loeblich and Tappan, *Planulina taylorensis* (Casey) *Marssonella oxycona* (Reuss), *Planoglobulina glabrata* (Cushman) and *Meterohelix globulosa* (Ehrenberg). The occurrence of Cretaceous foraminifera in younger rocks is a problem that still requires further study.

Similar foraminifera are found in Samar. Three localities contain species representing three different stages in the Upper Cretaceous. The lowermost and oldest stage, the Turonian, occurs in the vicinity of Mayube. *Globotruncana helvetica* Bolli G. *schneegansi* Sigal and *Rugoglobigerina rugosa* (Plummer) are described by Milagros Reyes and Elvira Ordoñez in 1970. A supposed Santonian assemblage with *Globotruncana concavata* (Brotzen), *G. renzi* Gandolfi, *arca* Cushman and *Rugoglobigerina* sp. occurs in San Jose. The uppermost or latest of the three is a Campanian-Maastrichtian assemblage composed of *Globotruncana lapparenti* Brotzen, *G. lapparenti bulloides* Vogler, *G. stuarti* (De Lapparent) and *Heterohelix globulosa* (Ehrenberg); this was found in limestone at Calape, Central Samar. The oldest assemblage comes in from a thin bedded limestone intercalated with manganiferous sediments and tuffs. In some places, the limestone has an underlayer of thin beds of chert. The Cretaceous unit which is gently dipping rests unconformably on eroded volcanics.

In the Sierra Madre Range, east of Manila, continuous sedimentation occurred from the Late Cretaceous to the Eocene period. The Late Cretaceous Kinabuan formation conformably overlies metavolcanics in Sampaloc, Tanay, Rizal. From this formation, Reyes and Ordoñez list 49 species of foraminifera. Conformably overlying the Kinabuan formation is a 2000 m. thick section of Paleocene to Eocene clastic sediments and black limestone. These rocks form the Maybangain Formation.

Rocks belonging to the base of the Tertiary, the Paleocene, had been found in Southern Palawan, and in the Bicol Peninsula in Caramoan, Camarines Sur. These rocks were dated by the presence of the small foraminifera named *Globoratalia velascoensis* (Cushman). In Palawan, this left-coiling foraminifera is asso-

ciated with *Globigerina velascoensis* Cushman, *Nodosaria clavaeformis* Neugeboren and several other genera. The fossils found in Palawan are also found in the Gulf and Atlantic Coast of the United States, Mexico, Peru and British West Indies. The keeled Globoratalias in Palawan indicate warm water of about 17°C. The sediments and bottom-dwelling species associated with the *Globoratalia* suggest environments at a depth of about 100 meters with access to normal open ocean currents.

Associated with the above foraminifera in Palawan is an algae which ranges from Paleocene to Lower Eocene—*Distichoplax biserialis* (Dietrich). This plant is found in the lower Tertiary of Austria, Czechoslovakia, France, Spain, Sicily, Oman, Persia, Morocco, Algeria, India, Pakistan, Borneo and New Caledonia. In the Philippines it is found in Caramoan Peninsula, Camarines Sur, Southwestern Albay, Southern Mindoro, Marinduque and Cebu, in addition to the Southern Palawan locality. It is often associated with various foraminifera such as *Discocyclina, Flosculina, Nummulites and Miliolids*. The association suggests that the limestones in which the fossils occur are reefal, bordering land masses. They also indicate warm, shallow, quiet waters protected from wind and waves. The environment could be a reef lagoon or the protected leeward side of a reef.

In Mindoro, an assemblage of Eocene algae also demonstrates that the climate in the Philippines was warm during the early Tertiary. The following algae were identified by Wataru Ishijima in 1969: *Archeolithothamnium mindorensis* Ishijima, n. sp., *Lithothamnium* cfr. *saipenense* Johnson, *L. marianae* Johnson, *L.* cfr. *aggregatum* Lemoine, *Mesophyllum vaughani* (Howe) Lemoine, *Lithophyllum* cfr., *compactum* Johnson, L. *kladosum* Johnson, *Corallina minima* Ishijima, n. sp., *C. cossmanni* Lemoine, *Corallina mindorensis* Ishijima, n. sp., *Jania* cfr. *miocenica* Johnson and Dasyclad algae. The genus *Archaeolithothamnium* had its greatest development during the Late Cretaceous to Eocene. Today the genus is restricted to warm waters with a depth ranging from less than a meter to 40 meters, 1-1/2 to 20 meters being the most common range. *Lithothamnium, Lithophyllum, Corallina,* and *Archaeolithothamnium* are also found in Eocene rocks in the Marianas Islands. *Lithothamnium* cfr. *aggregatum* Lemoine resembles algae found in the Oligocene of Algeria and Borneo. *Corallina cossmani* Lemoine is found in the Eocene of Malaysia

and in the Lower Miocene of Martinique while *Jania miocenica* Johnson is found in the Lower Miocene of Eniwetok and the Lower Oligocene of Borneo.

Therefore, as mentioned earlier, the sea was a medium through which cosmopolitan, genera were able to find a niche in the Philippines. Even during the Early Tertiary, 40 to 70 million years ago, the climate in the Philippines was already tropical. In Sabah, it was very warm and arid during the mid-Eocene period, such that excessive evaporation in landlocked bays precipitated salt with the red sediments of the Kulapis formation. F.H. Fitch in 1955 suggests that there was a desert environment in that area during mid-Eocene times. This environment could have readily extended into the Sulu Sea where anhydrite-rich sections are now encountered during offshore drilling for oil.

Although many of the areas described have swallow waters, there are also places where the sea is deep, as on the western side of Central Luzon. In the Late Eocene, the Aksitero formation was deposited in Tarlac; Pelagic foraminifera such as *Hantkenina alabamensis* Cushman, *Globoratalia centralis* Cushman and Bermucez and *G. cerroazulensis* (Cole) are described by Francisco Amato in 1964. The fauna and lithology indicate that the Aksitero formation was deposited in deep neritic to bathyal environment.

In the Early Tertiary seas in the Philippines, there existed a unique giant foraminifera. A fossil of this *Nummulite*-like organism was found in Buruanga Peninsula, Panay among limestone rubble. This enormous protozoan was described by Milagros Villavicencio in 1966 and she estimates the reconstructed test to be 206 mm. in diameter and 88 mm. thick. This surpasses the largest Nummulite studied which is *Nummulite millecaput* whose diameter is just a little more than 100 mm. Wataru Hashimoto in 1969, however, expressed some doubts on whether the specimen is of organic origin.

In addition to the foraminifera and algae, other organisms inhabited the Early Tertiary sea in the Philippines. In the Aksitero Formation, sponges and radiolaria were also reported by Amato. In Dasol, Pangasinan, a coral belonging to the genus Heliastraea was collected by Paul Fanning who reported this in 1912. In Marinduque, a sponge-like fossil named *Marinduqueia*

mirabilis Yabe and Sugiyama was found in Upper Eocene limestone. In the same area, a hydrozoan fossil, *Philippinactinia hasimotoi* Yabe and Sugiyama, was also collected from Upper Eocene Limestone. Underlying the Eocene coal in Catanduanes are shales with gastropods. Mollusc fragments are also found in the Caramoan peninsula among Cretaceous samples. In Northern Mindoro, Eocene sandstones and slates containing Nummulites also contain echinoderms and *Cardium* or *Anadara*-like lamellibranches. *Cardium* is the genus of the edible cockle locally known as *halaan*. East of Luzon, in Polilio, Eocene limestone contains algae and corals in addition to various foraminifera.

Although no remains of ancient fish and crustaceans, such as crabs and shrimps, have been discovered yet, these must have flourished in the warm seas and lagoons in the Philippines during the Cretaceous and Early Tertiary ages. On land, there must have been plants which provided the debris for Eocene coal and coaly horizons. With increased activity in coal and oil exploration, which may be foreseen in the coming years, this part of ancient Philippine biology will be illuminated, especially with the development of palynology, the study of pollen grains. These pollen could be used in correlating sedimentary rocks which are barren of invertebrate fossils.

A rich source of information on the plant life in the Philippines during this period comes from oil exploration. The diversity of flora observed during the Mesozoic, as discussed in the preceding chapter, persists into the Early Tertiary. The components of the floral assemblage, however, change as life evolves. Angiosperms have now appeared. The floral unity between Palawan and Recto Bank, along with the geology, the sequence of rocks and seismic evidence, show that during the Early Tertiary, land areas of the Philippines extended far westward into the shelf areas. Studies on the pollen buried in rocks now more than 2000 meters below sea level show that the floral zonation observed today had already been established during the Early Tertiary. Eocene inhibtants of the archipelago saw mangroves and beach forests along the shore. Lowland dipterocarp forests occupied inland areas while the highlands were covered by the lower montane forest and the mossy forest. In contrast to the assemblages found in the Jurassic and Lower Cretaceous, there were a great

many species and genera existing that are related to the plants that now inhabit the Philippines.

Drillings in Cadlao and the Recto Bank show that during the Late Eocene and Oligocene ages, various species of *Laevigastosporites* were predominant. The zone defined by *Verrucatosporites usmensis*, abundant in Cadlao, is found also in the Recto Bank and its presence indicates a Late Eocene age of the horizon in which it is found. Other plants found in the Early Tertiary of Palawan and the Recto Bank are *Zonocostites romonae, Retitricolpites crucipori, Verrutriporites lunduensis, Triorites minutripori, Ephedripites* sp., and *Psilatricolpites* sp.

Along the shores are mangrove and beach forests supplying material which eventually were transformed to coal. Familiar plants like *agoho (Casuarina)*, pandan and the fern *Acrostichum* are found in these near-shore environments. At least three types of spores of the common fern *Pteris* are present. A relative of the nito *(Lygodisporites)* has now been found, as well as tree ferns of the *Cyathea* type, found in the Mesozoic of Mindoro, Palawan and the Recto Bank.

Palms also fringed the shores just like they do today. Pollen from extinct species of the genus *Nypa*, which includes the economically useful *nipa* palm, *Spinozonocolpites echinatus* and *S. baculatus*, has been recovered from the Recto Bank. Pollen of *Proxapertites operculatus*, another extinct palm, possibly related to Nypa, has been recovered from Cadlao and Recto Bank. Various species of *Dicolpopollis*, including *Dicolpopollis malesianus* and *Dicolpopollis* cf. *elegans*, also inhabited the Philippines. These plants show an affinity to *Calamus*, the genus of *uay* or rattan, an important plant used today for making furniture and for constructing shelter, as seen in nipa huts. It is also possible that *Dicolpopollis* is comparable to *Metroxylon*, the genus of the sago palm. Pollen of the uniquely shaped fishtail palm, *Caryota*, has been recovered from offshore wells. This palm and the sago palm are sources of starch. *Discoidities borneensis*, which corresponds to *Brownlowia* or Pentace of the Tiliaceae, inhabits the back-mangrove.

Dipterocarp pollen are recovered from the Eocene in offshore wells suggesting that further inland there is a lowland dipterocarp forest. Among the genera represented are *Canarium, Ani-*

soptera, Dipterocarpus, and a *Palaquium* type. The pili nut belongs to the genus *Canarium,* palosapis belongs to *Anisoptera* while alakaak is known scientifically as *Palaquium gigantifolium. Kalipaya (Palaquium ahrenianum)* is the guttapercha tree. At higher elevations, *Dacrydium* pollen and *Pinuspollenites* are produced. Also found are pollen of the *Lithocarpus* type, *Quercus* and *Sequoia.*

Dacrydium and *Floreschuetzia levipoli* are restricted to the Neogene over large areas in the Sunda shelf but these must have had an extended range reaching to the Paleogene in Southwestern Philippines. Many of the pollen species found in Palawan and the Recto Bank are also found in the Cretaceous to Eocene of the island of Borneo. As in Palawan and the Recto Bank, tropical elements are found with temperate species such as the *Pinuspollenites* and the *Alisporites similis* in Sarawak so that it can be inferred that nearby mountain chains are also found in Borneo. Among the species found in Borneo and in Southwestern Philippines are *Classopollis* sp. cf. *classoides, Zonalpollenites* sp., *Cicatricosiporites* cf. *dorogensis, Appendicisporites tricornitatus, Spinozonocolpites echinatus, S. baculatus, Proxapertites operculatus, Dicolpopollis malesianus, D. elegans, Triorites minutipori, Discoidites borneensis, Psilatricolporite acuticostatus, Striatricolpites minor, Gingkocycadophytus nitidus Retiricoolporites crucipori, Exesipolelnites tumulus* and *Araucariacites australis.* The large number of common flora indicates the close relationship of the Philippines with Southeast Asia even during the Paleogene age. There are some slight differences as in the extended range of *Dacrydium* and *Floreschuetria levipoli* in the Philippines. In Sarawak, Jan Mueller in 1968 notes the absence of *Dipterocarps.*

The tropical elements of the flora of the Philippines and its Southeast Asian neighbors dominated large portions of Eurasia and Africa during the Paleogene period and perhaps even earlier. The presence of tropical flora in Britain was described by Reid and Chandler in 1936. In the London Clay, tropical flora belonging to the following families are present: Annonaceae (the *atis* or Custard Apple family), Anacardiaceae (the family of the mango, cashew and the *siniguelas),* Apocynaceae (the family of *kalachuchi* or frangipani, *Adelfa* or sweet-scented oleander and *tsitsirika* or tropical periwinkle), Buxaceae, Burseraceae (the family of pili nut, *Canarium ovatum*), Dillenia-

ceae (the family of katmon, *Dillenia philippinensis)*, Elaeocarpaceae, Icacinaceae (the laurel and cinnamon family), Meliaceae (the *santol* and *lansones* family), Menispermaceae (moonseed or makabuhay family), Myrsinaceae (family of *ardisia* or *pilapil*), Palmae (the palms), Sabiaceae Sapindaceae (the *rambutan* and lychee family), and Sterculiaceae (cacao and coffee family). Of the 70 genera in the London Clay, 97% belong to the families mentioned and 61 to 73% show very close relationship to present-day Indo-Malesian flora with only 5% related to temperate flora of Europe, North America and East Asia. This Indo-Malesian flora was widely distributed during the Paleogene. The shores of the extensive sea known as Tethys was therefore fringed by vegetation closely allied to plants of the Philippines and Southeast Asia. Michael Zohary in 1973 concludes from its wide distribution that this Indo-Malesian flora was also found "quite away from the shores of the Tethys." The flora reached the 50th parallel during the Eocene but it was driven southward during the succeeding Tertiary epochs. From the Oligocene, there was a decline in the tropical elements in Europe and Western Asia. Remnants of the tropical Indo-Malesian flora are found today in the Middle East and lower Egypt.

During the Cretaceous and Paleogene, a change in the flora in the Philippines was observed. This indicated relationships with nearby areas in Southeast Asia. This flora spread to other parts of the world and, according to Zohary in 1973:

> A tropical flora of the Indo-Malesian type occupied parts of Africa south of the Tethys and considerable broad land belts north of it during the Cretaceous. There is adequate evidence to support the opinion expressed by Chandler (l.c.) and Channey (l.c.) that this flora, originating in tropical Asia, advanced in two branches along the northern and southern shores of the Tethys so that at some time it must have covered practically the whole land surface of the Middle East.
>
> ...We do not know exactly when this flora entered Africa, but it seems from Chandler's data to have existed in the Upper Cretaceous and the Eocene of Lower Egypt.

> ...This flora became later partly replaced by another old African xero-tropical savanna flora of the Acacia-Combretum thorn-bush type, termed by some authors (see Monod 1957) the Paleo-African flora...
>
> ...The invasion of Africa by the Indo-Malesian flora was probably incomplete not only the modern Congo-Guinean region, but also the corresponding latitudes of East Africa, as evidenced by the findings by Krausel, Stromer, Hirmer, Chandler and Chiarugi cited above. From these and similar findings in S. Palestine (Lorch and Fahn 1959 and unpublished), it could be suggested that the area of the Indo-Malesian flora might have begun shrinking in Africa at the end of the Paleogene, until it assumed its recent extent on African territory (the Congo-Guinean region).

The Indo-Malesian flora dominated West and Central Europe during the Eocene but climatic changes brought about the decline of the tropical flora in Europe.

Thus, during the time of evolution of mammals in Africa and Eurasia, vegetation originating from tropical Asia was predominant. A tropical climate was widespread. In the Philippines, mangrove swamps, beach forests and other types of forests existed and these contained plants that could be used as food and shelter.

To further unravel the environment and history of this period, let us now examine more closely the record of the rocks in the Philippines and neighboring areas.

When we examine the record of the rocks formed during this period of Philippine geological history, we observe a preponderance of submarine volcanic rocks such as spilites and keratophyre associated with sedimentary rocks such as graywackes, which are indicative of rapid erosion and deposition, and shales which are deposited in a quiet environment. There are also ultramafic plutonic complexes. Towards the end of the period, more silica-rich igneous rocks such as diorites, and volcanic rocks such as dacite, were emplaced or extruded as the case may be. Limestones containing the fossils already discussed were also found in some areas.

The early stages of the development of the Philippine archipelago are therefore characterized by volcanism and an unstable crustal environment. The Philippines during this time can be presumed to have been shaken by earthquakes and in some watery areas, now dry land, the cold, dark abyssal depths of trenches were formed. Similar conditions prevailed in nearby Sabah and Taiwan.

Widespread volcanism during this period flooded large areas of the Philippines with basaltic rocks. Extrusion of these rocks under seawater altered these into greenish rocks called spilites. These spilites and other submarine volcanic rocks are common in the Central Cordillera of Northern Luzon, including the province of Ilocos Norte. These also underline the Sierra Madre Range along the east coast of Luzon. In this range and in the Zambales Range in the west, we also see ultramafic masses associated with the Cretaceous-Paleogene spilites and graywackes. These ultramatic rocks consist of silicates rich in iron and magnesium.

The volcanic environment can be traced southwards to the Bicol peninsula. In Catanduanes, the Yop formation consisting of submarine flows, volcanic breccia, diabase porphyry and intercalated chert and volcanic graywackes unconformably overlies the Jurassic Catanduanes formation. The Yop formation possibly intertongues with the Bonagbonag limestone which is Cretaceous. This association of rocks suggests that a volcanic island developed on the pre-Cretaceous rocks and these were fringed by limestone reefs. Similar association of Cretaceous-Paleogene rocks overlaying pre-Cretaceous metamorphic rocks are also found in Camarines Norte and Quezon.

As we go further south, we also encounter spilitic rocks in Samar, southern Leyte, Negros, Cebu, Bohol and the island of Panay. These are also found in many places in Mindanao, such as Agusan, Surigao, Zamboanga and South Cotabato. The volcansim also affected regions in the Philippines as far west as North Central Palawan. As in Catanduanes, the faulted and folded altered flow overlie unconformably Jurassic parachists, a type of metamorphic rock.

Commonly found in the spilites are beds and patches of red chert a rock consisting of silica and siliceous shale. The latter rock consists of clayey sediments. This association suggests that

the basin of deposition was deep and quiet, far below the reaches of wave action and far removed from the sources of land-derived, coarser clastic debris sediments.

Also commonly associated with the altered submarine lava flows are beds of a variety of sandstone called graywackes. In the Philippines, the composition of this rock bears strongly the imprint of the volcanic terrains supplying the clastic debris underlain by volcanic rocks that form fresh additions to the crust drawn from the earth's interior.

Where did these ancient mountain ranges lie? The most probable sites are those places where there are deep-seated rocks such as those found in metamorphic terrains, ultramafic complexes and also the areas where Paleogene plutons now crop out. As noted in the previous chapter, the metamorphic rocks are scars of ancient mountains. We could also say the same about ultramafic terrains, for these are originally formed in the mantle of the zone of the earth underlying the crust. Under the oceans, the crust has an average thickness of four kilometers while under continents, the crust is much thicker. A large uplift is therefore required before mantle materials can be exposed at surface level.

The ultramafic complexes have been exposed to the extent of 11,500 sq. kilometers in area or 3.8% of the total land surface of the Philippines. These complexes which were emplaced in the Cretaceous and Early Tertiary consist of prioditite, dunite, serpentinite and gabrro closely associated with the spilites, chert and graywackes. This association, known as the ophiolite suite, is commonly found in orogenic belts, or zones of active mountain-building, of other places and other times. Similar complexes are found in Borneo where they are thought to have been emplaced during the Eocene or earlier. These belts in Sabah can be traced to the southwestern areas of the Philippines such as Tawi-Tawi, Zamboanga and Palawan. In addition to the outcrops in Zambales and the Sierra Madre Ranges, there are also occurrences in the eastern coast of the Philippines along the Bicol Peninsula, in Samar, Homonhon, Surigao and the Pujada Peninsula, Davao. A western belt extending from Zambales to Mindoro and Antique is also present.

The close association of ultramafic complexes, having compositions similar to the zone called the mantle, with submarine vol-

canics and sediments is consistent with the hypothesis that this is a sequence of oceanic crust and the upper mantle. The Zambales ultramafic complex would therefore by a portion of the upper mantle while the spilites and marine sediments in Pangasinan and Tarlac would correspond to the overlying oceanic crust. This section is now tilted with the top turned towards the east.

Areas such as this are of great value to science because we observe here a cross-section that had been thrust out of great depths. Many geological processes such as magnetism and tectonic movements originate from the mantle. One of the pet dreams of scientists is that of undertaking the Mohole project, which consists of making a deep drill-hole which would pierce the Mohorovicic discontinuity and reach the upper mantle. Here in the Philippines, the upper mantle is already exposed. A careful study of these complexes will produce important contributions to science.

Structures within the Zambales ultramafic massifs show complicated and sinuous layering which may have been brought about by compressional stresses that accompanied the emplacement of these rocks. These compressive stresses must have ceased long before the advent of the Oligocene because undeformed dikes in the Zambales massif have been dated radiometrically to be of the Oligocene age. An unconformity between the Upper Eocene Aksitero formation in Tarlac with the underlying volcanics is also consistent with the pre-Upper Eocene age of the Zambales complex.

Siliceous plutonic rocks are found under some ultramafics in Coto, Zambales. This configuration is also found in Jose Panganiban, Camarines Norte and also in the Darvel Bay area, Sabah. These could be portions of continental material thrust under the block of mantle material as it was being emplaced.

The sequence of events in the vicinity of Zambales could therefore be summarized as follows:

1. Building up of crustal material of sialic composition during the pre-Cretaceous.
2. Compression, emplacement and uplift of mantle material before late Eocene.
3. Erosion followed by downwarping.

4. Deposition of the Aksitero formation under bathyal conditions.

The downwarping also marks the beginning of the Central Valley basin of Luzon.

During the time when erosion was taking place in the west, that is, Eastern Luzon, especially along the Sierra Madre Range, the area east of Manila was under seawater from the Cretaceous to the Eocene. Inasmuch as Cretaceous to Paleogene spilites and metasediments can be found under the young tuffs and basalts in the Antipolo plateau, Montalban and Eastern Rizal and Laguna, it is very probable that under the young volcanic cover which forms the foundation of most of Metro Manila, there are rocks which were under the sea during the whole time dating back to more than 70 million years. Since then, there were large vertical movements that lifted these submarine rock masses to form land and the majestic ranges seen east of Manila.

Further to the East, from Polilio to Catanduanes, there was invasion and regression of the sea during this period of Philippine pre-history. An unconfirmity between the Eocene Babacolan formation and the underlying Bislian quartz diorite, Lubi formation and Masisi schist in Polilio shows that there was land in Eastern Philippines by the time the Eocene age began. Similarly, in Catanduanes, we find a pre-Cretaceous land surface buried by Cretaceous marine sedimentary and volcanic rocks. Subsequent regression eventually allowed coal to form at the start of the Eocene age.

A more detailed description of the geologic history of Catanduanes and its adjoining areas can be gathered from this account by Victor de los Santos and J. Marvin Weller published in 1955:

> "Pre-Tertiary strata of the Hitoma-Manambrag region appear to have been deposited in a rapidly sinking trough under conditions suggesting geosynclinal environments. The extents of this trough and its relations to contemporaneous land are not known but the trough probably was not of great size and land probably existed nearby. During Bonagbonag time the land was low and contributed little clastic material to this region. However, a considerable thickness of deposits that formed cherty unfossiliferous limestone did accumulate. This epoch was terminated either by uplift of a nearby vol-

canic terrain or, more likely, by the outbreak of intensive volcanic activity in a nearby region. In either case very rapid erosion furnished vast quantities of unweathered basic sediments. This material, largely sand, was deposited in shallow water far enough from the coast to prevent transportation of pebbles. Much of the trough sank rapidly but compensating deposition kept it almost full. Conditions, however, were unstable; basic magma was injected into the accumulating sediments and burst through in places to form submarine flows. Locally, parts of the trough were deformed and uplifted and recently deposited sediments were eroded and redeposited. Sand so derived cannot be identified but boulders that could not have been transported far are evidences of this activity. Some areas were raised and eroded so extensively that recently emplaced intrusives were laid bare; even the Bonagbonag limestone was brought to the surface, and boulders of both kinds of rock were moved short distances and buried in fresh sediment.

"The Pre-Tertiary episodes were terminated by uplift, folding, and possibly faulting. The structures developed at this time are not known but pressure was sufficient to result in firm induration and perhaps slight metamorphism of clastic sediments and much shearing in limestone. This was followed by erosion and the development of a land surface probably of moderate relief and rounded contours. Great thicknesses of rock seem to have been removed in some areas.

"The region of Catanduanes subsided in Eocene time, and subsequently a variety of sediments accumulated under diverse shallow-water conditions. The extent of the resulting basin of deposition is not known, but Eocene deposits were formerly much more widespread than they are today. The Hitoma-Manambrag region does not appear to have been near sediment-producing land, or nearby land was low because of subsidence or extensive previous erosion of the region that furnished the sands of the Cabugao graywackes. At first, water was very shallow and several slight fluctuations of sea level resulted in the temporary partial drainage of the Hitoma-Manambrag region and the development of swamps in which peat accumulated. Slightly more rapid subsidence produced conditions in which lime mud and various

types of animal debris collected and were converted into limestone. Reefs may have been built up. Later, land derived clastic sediments again reach this region; and with variations from place to place and from time to time, produced a stratigraphic section of unknown thickness in a correspondingly subsiding basin. This accumulation of normal types of sediment furnished by the weathering and erosion of the land may have continued constantly or with several interruptions until the end of the Tertiary period, or it may have terminated any time after the Eocene."

Since the foregoing account was published, however, Federico Miranda and Bassanio Vargas have added in 1967 something when they showed that the Bonagbonag limestone was Cretaceous. We may also correlate the sequence of graywackes-submarine volcanics overlain by shallow sediments—coal-limestone—with the sequence of *flysch* followed by *molasse* commonly found in geosynclinal environments and cycles. The flysch constitutes sedimentary and igneous rocks deposited during the early stages of geosynclinal evolution whereas the molasse formed after the pulse of mountain-building and uplift. The land areas mentioned in the account could have been the pre-Cretaceous basement of Catanduanes and of the nearby Caramoan peninsula.

The foregoing narration of the geologic history of the country shows how complex the events were in a limited area of the Philippines. These events were induced by geological processes that affect broad areas and hence similar complex events presumably were repeated in other parts of the archipelago.

The record of the rocks therefore shows a prolonged period of basaltic volcanism which either covered or fragmented an older, truncated Paleozoic-Mesozoic land surface. The rocks bear witness to a change from a terrestrial environment to the cold, dark, abyssmal depths of the sea. These deep troughs are filled by lava flows and by sediments derived from adjoining mountain ranges. Some portions were eventually uplifted again. Along shallow areas, algae, corals, sponges and various marine organisms proliferated to form limestone reefs. Some swamps also developed close to the shoreline.

As mentioned earlier, the mountainous areas may also be delineated by siliceous intrusives formed during this period. The

oldest intrusive thus far dated rediometrically by the potassium-argon (K-Ar) method comes from the Taon River, in the Bislig-Lingig area, Surigao. The rock is an altered quartz diorite with a radiometric age of 129 million years. If the age is correct, this magmatic episode may be correlated with Cretaceous events that took place in Malaysia and Indonesia. In the tin fields of Phuket, intrusives give early Cretaceous rubidium-strontium ages and 56 million years by the K-Ar method. Granitic rocks in Central and South Sumatra and in offshore areas of Java have been dated to be 100 million years old. During the Late Cretaceous, granitic rocks were intruded in the islands of Tioman, Anambas, Natuna and Trung Lon.

In Surigao, along the Agusan river, a quartz diorite gave a radiometric age (K-Ar) of 60 million years. This is close to the ages determined from intrusives in the Central Visayas where an age of 59.7 million years was determined from Central Cebu and a 59 million-year-old intrusive collected from Guimaras Island between Panay and Negros.

In Eastern Luzon, intrusives from the Sierra Madre Range in Quezon were dated to be Eocene with ages between 43 to 47 million years. In Polilio, a quartz diorite is overlain unconformably by Eocene rocks. Schists in Rapu-Rapu give a K-Ar age of 42 million years.

These still scanty data suggest that there were at least two groups of magmatic events producing siliceous intrusives during this period. The earliest may have been pre-Eocene and could have started as early as 129 million years ago. Another episode took place 59 to 60 million years ago in the Central Philippines and Eastern Mindanao. From 42 to 47 million years ago, the locus of plutonic and thermal events shifted to Eastern Luzon.

Additional data may change or confirm the patterns we see today. However, the occurrence of these siliceous plutonic masses indicates that there were already land areas, perhaps even then forming islands like those found now. Some of these Paleogene plutons have gneissic layering and this could be evidence of derivation from older, continental sediments. Contrary to the common concept often stated in international literature that the major portion of the Philippines consists of basic volcanics and sediments and that it is a good example of transformation of

oceanic crust to a more continental crust, these siliceous plutons in the center and the margins of the Philippine archipelago show that sialic material was already present even during the early stages of archipelagic development. Siliceous volcanics such as dacite were already present in the Eocene of the Sierra Madre in Eastern Rizal, Marinduque, Panay and Samar.

The development of Paleogene intrusives in the Eocene may be related to the violent, mountain-building upheaval that visited the Philippines towards the end of the Eocene. This catapulted the Cretaceous-Paleogene rocks as far west as Balabac Island where the Chert-Spilite formation was steeply dipping and eventually overturned. This is in contrast to the overlying Miocene sandstones which were gently folded. This uplift resulted in the exposure of Eocene rocks over large areas. Hence, even in Western Palawan which today is underwater, there was exposure of Eocene shales to the processes of erosion. This preceded the subsequent submergence of the area which now contains valuable oil reservoirs in Lower Miocene rocks.

This early Tertiary mountain building or orogenic event is a global phenomenon. In the Pacific, a bend in the chain of volcanic mountains, which rises above the sea as islands, is correlated to a shift of the sea-floor, spreading patterns that took place about 40 to 42 million years ago. The bend is interpreted as resulting from the shift in the direction of the spreading of the Pacific ocean plate from a northwesterly to a westerly direction. Such a change in spreading patterns would also account for the contrast in the folding patterns between Early Tertiary and the younger rocks in the Philippines. Cretaceous and Paleogene rocks show a northeast trend of fold axes whereas Neogene and younger rocks show a dominant north-south trend of fold axes. These patterns, in turn, influence the elongation of mountain ranges and affect the shape of some islands of the Philippine archipelago. The global early tertiary orogenic event may have also influenced world climate. In the northern hemisphere, early Tertiary climates are inferred by Jack A. Wolfe, from a study of plant fossils, as warm and equable up to Eocene times. A rapid deterioration occurred in the early Oligocene with the sharp drop of the mean annual temperature at high latitudes. Wolfe refers to this climatic change as the "terminal Eocene event." He notes that in the Southern Hemisphere, this climatic event

is closely associated with the initiation of cold bottom water in the oceans as disclosed in another study by J. P. Kennet in 1977.

This age of intrusions in the Central Visayas during the Paleogene could be related to the plate movements at this time. Tai-chang Shih in 1978 reported that the crust of the West Philippine Basin started to form earlier than 59 million years ago, probably at the ridge which was the southern boundary of the Pacific plate at that time. This observation is based on the findings on the magnetic patterns of the sea floor. These patterns also indicate that the West Philippine Basin has drifted north about 20 to 30 degrees and has undergone a clockwise rotation of 50 to 60 degrees since 40 million years ago, the time during which the West Philippine "marginal basin" formed offshore the island of Polilio. On the Benham Rise, the sea floor is at least 38.2 million years old as indicated by K-Ar dating of a basalt sample from the Deep Sea Drilling Project Site No. 292. Spreading of the ocean floor continued into the Neogene. Opening of the eastern boundary of the basin at about 25-1/2 million years ago formed the Shikoku basin. Spreading stopped in the southern part of the Shikoku basin 16 million years ago whereas it ceased in the central and northern parts after 14-1/2 million years ago.

The activity of plate movements during the Paleogene is part of the global reorganization of plates during the Early Tertiary. Peter Rona and Evan Richardson in 1978 noted a change in the motions of plates which occurred mainly during the Eocene epoch, 53-1/2 to 37-1/2 million years ago. At this time, patterns shifted from those which predominated during the Mesozoic. Rona and Richardson attribute this major reorganization of plates to the increasing resistance along east-west trending plate boundaries. This would force the system of plates to reorient along lines of less resistance.

The Cretaceous-Paleogene unit affected by the orogenic event in the early Tertiary formed the foundation over which younger rocks were deposited. In some areas, deformation resulted in subsidence, in such a way that Oligocene sediments started to be deposited in basins, for instance, in the Cagayan Valley Basin and the Central Valley Basin. By the end of the Eocene, the Philippines had been transformed into an archipelagic environment, a form which has persisted up to historic times. This is

the environment which greeted prehistoric Filipinos and our ancestors upon their arrival. In addition to forming the foundation for younger rocks and providing a source for clastic sediments which filled up the troughs and basins formed by the orogeny, rocks formed during the Cretaceous to Paleogene times are still important to Filipinos and to mankind because energy and mineral resources are derived from them. An understanding of the environment and the events in those distant ages will help in the search for these natural resources and their development for the benefit of the present and future generations of the Philippines and the world.

The formation of coal during this time has already been described. In addition to coal, traces of oil and gas are found in Eocene rocks of Southern Mindoro and it would not be surprising if Eocene and older sediments were to be found containing commercially recoverable oil and gas deposits. There are also Eocene and older reservoirs that are targets for exploration west of Palawan.

In Camarines Norte and Samar, rocks of this period have been found to contain a significant amounts of uranium. Development of radioactive mineral resources is vital to the current energy program of the New Society.

The Paleogene intrusives just discussed are the host of vast amounts of copper and gold, metallic minerals which are important exports, generating foreign exchange and capital essential to various national development programs.

The largest deposit of copper is found in Cebu where over a billion tons of ore have been discovered. Atlas Consolidated, a mining company, currently extracts from Paleogene host rocks 100,000 tons of copper ore with gold, copper and molybdenum as by-products. These large reserves and the rate of production make Atlas one of the biggest mines in the world.

In Paracale, Camarines Norte, a Paleogene granodiorite forms the host for gold-quartz veins that may exceed one kilometer in distance and reach a depth of 600 meters. These veins are the source of gold which even the pre-Spanish Filipinos mined as placers.

In the ultramafic rocks, substantial deposits of refractory chromite and significant amounts of metallurgical chromite are present. Platinum and other noble metals are associated with the latter type in Acoje, Zambales. Zambales is the most developed area and in this province occurs the biggest reserves of refractory chromite in the world. The ultramafic rocks are also the source of nickeliferous laterites which today are mined for nickel in Nonoc, Surigao. Nickel is a new mineral product which has joined copper and gold in this decade as an important metallic mineral product of the Philippines. In the future, the laterite may also become a source of iron which is essential to industrialization in this modern age.

Massive copper-lead-zinc-silver deposits are also found with the Cretaceous-Paleogene volcanics and their metamorphosed equivalents in Bicobian, Isabela; Rapu-Rapu, Albay; Balabac Island, Palawan; Samar, Pangasinan and other places. Although small when compared with the tonnages of porphyry copper deposits like those of Atlas, these deposits have higher copper content as well as other metals, in such quantity indeed that these may also be mined. Development of these deposits will provide sources of other base metals as well as employment for Filipino miners.

Non-metallic mineral resources are also found in rocks of this period. Alteration of the ultramafic rocks produced serpentine or asbestos. Some masses have metamorphosed into talc schists. Metamorphism of limestone provides sources of marble. Construction material is also derived from the Eocene black limestone.

It is therefore obvious that events that took place more than 40 million years ago relate to current events and affect programs for the future. These resources are non-renewable and it required a special set of circumstances for these uncommon earth resources to form. The Philippines is fortunate that events in the Cretaceous to Early Tertiary times led to favorable accumulations in some areas. These are part of a national heritage that we must utilize wisely with the needs of future generations always in mind.

The Cretaceous to Early Tertiary period just covered here spans more than 90 million years. Reptiles give way to mam-

mals, flowering plants appear, diverse marine organisms are seen in Philippine rocks. We have also seen a marked change occurring in the geologic environment as shown by the shift from a more continental environment with widespread basaltic volcanism during the Cretaceous to the early Tertiary period. This period culminates with a violent upheaval which set the stage for the deposition of succeeding Later Tertiary rocks. There is still much that earth scientists can learn from this important episode in the prehistory of the Philippines and a clearer understanding of it will benefit the Philippines and the world.

Chapter Four

The Neogene:
THE VARIETIES OF LIFE AND NATURE'S TREASURES

A period of accelerated evolution and diversification came toward the middle of the Cenozoic era, 25 to 40 million years ago. During this time mammals rose to dominance over earth's life forms. In many countries evidence of the earliest species in man's ancestry is found in rocks 10 to 25 million years ago, although in at least one country, in Egypt, similar evidence has been found in fossils dating back to 30 or 35 million years ago. In that time, the middle of the Cenozoic epoch, the environment was favorable to the further development of man's first forebears, which consequently spread throughout the planet. Tectonic events brought changes both in climate and in habitat, demanding the development of greater intelligence and agility among man's ancestors. At the same time, various other mammalian forms, both marsupial and placental, evolved and proliferated. Some of these have become extinct, or are a dwindling species; many are still around,

a great number of them in the Philippines, where their fossils have been found. Fossils of various forms of marine life, from molluscs to sharks, also abound in the Philippines. Studies of these fossils inevitably led to the unravelling of the conditions that developed as a result of changes in earth structures and formations in the Philippines which affected both land and sea and their respective varieties of life. An analysis of these changes as they are recorded in the rocks calls attention to their influence upon the development of life in the Philippines, and their relationship to contemporary man.

THE rise of mammals to dominance, initiated in the Late Cretaceous and continuing to Early Tertiary, persisted through the Mid-Cenozoic. The warm, equable climates during the Early Tertiary became slightly colder later but twenty-five million years ago summer-like climates prevailed in the middle latitudes that are now temperate. Even the Arctic was warm and without glaciers. Subtropical environments during this time favored the dispersal of mammals that were evolving, including man's early ancestors.

The earliest species in man's primate lineage, *Dryopithecus* (from the Greek for oak and ape), have remains buried in the Miocene rocks of many countries. However, dryopithecine remains in Mid-Oligocene rocks (30 to 35 million years before the present) have been recovered in Fayum, Egypt. In Northern Egypt, these ancestral apes probably flourish in a mixed environment consisting of forests fringing the delta of the ancient Nile. Away from the flood-plain and on higher level topography flourished an open savanna and semi-desert vegetation. The dryopithecine apes drowning in the Nile and its tributaries were washed away and buried in the channel and longshore sands, thereby preserving their remains near Fayum, Egypt.

The dryopithecines found the mid-Cenozoic environment favorable and they were able to spread out and survive for 20 million years. By Miocene time, the dryopithecines had reached France, Spain, Germany, Hungary, Greece, East Africa, Pakistan, India and China. However, tectonic events during the Middle Miocene touched off the start of a gradual and general decline of temperatures in the middle latitudes. A graphic idea of the temperature characteristics during the Cenozoic may be gathered

from the plate entitled "Variations of Mean Temperature during the Cenozoic." Along with the changing climate came a transformation in habitat, from a subtropical forest to temperate woodlands and woodlands savanna. At about this period, 10 to 15 million years ago, as the fossil record shows, the dryopithecines gave rise to three other genera — *Sivapithecus, Gigantopithecus* and *Ramapithecus*. Among these, *Ramapithecus*, which was first found in the Siwalik Hills of Northern India and named Rama's ape, has shown the greatest similarity to later hominids.

The wooded savanna which replaced the tropical and subtropical forests did not provide adequate food supply. This exerted an environmental pressure favoring the survival of individuals capable of alternative food gathering. Thus, tree dwellers were driven to the ground in search of food. These environmental pressures persisted through the Pliocene during which other hominids appeared. Man's evolution will be covered in greater detail in Part 2 of this volume.

The mammals contemporaneous with these ancestral primates were different from those with which we are familiar today. Marsupials occupying North America were pushed southward by placentals that migrated from Asia along land bridges connecting these two continents. From South America, these mammals reached Australia through the Antarctic. During the Neogene, the major group of the Australian marsupials was established. Gigantism occurred, making possible the growth of a kangaroo to a height of more than three meters, but this disappeared before the Pleistocene.

Among the placentals, evolution and diversification also brought about changes in the predominance and proportion of different groups. The odd-toed mammals or perrisodactyls, to which the horse and rhinoceros belong, started to decline during this time. A primitive perrisodactyl, the tapir, was more widely distributed during the Mid-Cenozoic but later glaciation pushed it southwards. The tapir is now confined to Malaya and South America.

The ancestor of the horse which was the contemporary of the dryopithecines and *Ramapithecus* was a dwarf compared with the modern-day *Equus*. The well-documented evolution of the horse shows several trends. These include an increase in size,

changes in the teeth, lengthening of the face to accommodate changes in the teeth, lengthening of the legs, a decrease in the number of toes, and an increase in the complexity and size of the brain. From the *Hyracotherium* or *Eohippus* that was the size of a small dog when it appeared in the Early Tertiary, the three-toed *Miohippus* developed. From the *Miohippus*, several three-toed grazers developed including the *Mercyhippus* which was about as big as a pony. By Pliocene time the *Pliohippus*, which had a single toe, evolved from the *Mercyhippus*. This Pliocene horse is the direct ancestor of the modern horse which appeared in the Pleistocene. This beast of burden, which has played an important part in the military, agricultural and other domestic activities of man, has a lineage that goes back to more than 60 million years ago.

Another perrisodactyl, the rhinoceros, also had a dwarf ancestor. However, during the Oligocene and Early Miocene, the *Intricotherium*, more than five meters tall, evolved and its remains are found in South Russia, Baluchistan and Mongolia. Unlike the modern rhinoceros, these did not have horns. Various one- and two-horned rhinoceri appeared during the Miocene. Some representatives of this type reached the Philippines during the Pleistocene.

As the perrisodactyls declined, the artiodactyls or odd-toed mammals diversified and became predominant in the plains and forests of the Neogene. Some of the early forms were small with, however, indications of increasing in size as evolution progressed. Early elephants were even then already large. Instead of the two tusks of present-day elephants these elephantoids had four tusks. The Mastodon, abundant during the Pleistocene, first appeared during the Miocene. Elephants were found in the Philippines during the Pleistocene.

The artiodactyls include cattle, goats, and sheep, animals that are important sources of food and clothing material. These first appeared during the Miocene but their diversification began only in the Pliocene. They are now the most abundant and varied among the mammals.

The carnivores preyed upon the other mammals. The modern-day carnivores evolved from the early miacids which radiated into three branches, one cat-like, another dog-like and the

third in the form of marine carnivores, like the seal and walrus. During the Miocene, the dog family branched out to merge with another group, becoming heavier and shifting towards a less fleshy diet. This group evolved into the bears and pandas. The cats, on their part, had become very efficient carnivores even during Oligocene time. Development of long canines resulted in the saber-tooth types which evolved during various stages of the Cenozoic.

Numerous descendants of the early miacids are found in the Philippines today. Skunks, otters, and mongooses are found in Palawan; the weasels in Palawan and the Sulu Civets and wild cats show that there has been a wide distribution of these animals in Philippine forests.

Geologic events that affected climatic patterns also re-arranged the biogeographic provinces of the sea. Oligocene diastrophism resulted in the breakup of Tethys, the ancient sea which girdled Eurasia and Africa. The Oligocene event separated the western portion of Tethys from the Indo-West Pacific province. The land bridge through which marsupials migrated to South America disappeared for most of the Neogene, thereby isolating South from North America and connecting the Eastern Pacific with the Atlantic. This land connection was reestablished during the Pliocene and once more, the two oceans became separated.

As the unfolding of the symphony of life progressed, some forms survived, others became extinct and new ones appeared. In the Paris Basin, the proportion of marine invertebrates, especially the molluscs, surviving today was correlated by Charles Lyell in 1833 with the age of the Tertiary rocks in the basin Lyell originally subdivided the Tertiary into the Eocene, Miocene and Pliocene, with the Eocene fossil fauna having only 1-5% of recent species; the Miocene, 20-40%; the Older Pliocene, 50-90%; and the Newer Pliocene, 90-100%. The term Pleistocene was subsequently introduced by Lyell for the Newer Pliocene.

The applicability of the Lyellian percentages to the Philippines was tested in 1921 by Roy Dickerson. At that time the percentages system as proposed by Lyell and G. P. Deshayes came out as follows:

Epoch	*Percentage of Recent Species*
Eocene	0
Oligocene	3
Miocene	25
Pliocene	60
Pleistocene	90

Dickerson studied the molluscan fauna of the Miocene Vigo group in the Bondoc Peninsula, Tayabas (now Quezon Province). Of the 98 forms that were specifically determined, 74 or 75.5% are living species, with the extinct forms confirmed to be common to the Upper Miocene of Java. It is interesting to note that *Placuna placenta* Linnaeus, the source of shells used in window panes and as various ornaments, was among those collected in the Miocene of the Bondoc Peninsula. There are many familiar shells (see the list in the appendix) in the collection, among them cowries (locally known as *sigay*), arks, cones, oysters, volutes, pecten, and tritons. Corals and echinoid remains are found with the molluscs. Some localities indicated brackish water yielding only a few specimens which were probably brought by "small crabs that sidled over the sands of the Vigo Sea." Amber, petrified wood and carbonaceous material are found in this locality. Other localities, however, indicated that the fossils lived in the shallow inshore waters of an inland sea.

Many geologists and paleontologists who studied Miocene rocks in the Philippines during the early part of this century recognized a faunal unity in various areas today, despite being spread far apart. The resemblance to the Vigo fauna led them to use the term interchangeably with Miocene. Hence, Vigo rocks were found in the north in Benguet, in the west, in Mindoro and as far south as Cotabato. In Southern Mindoro, a shark's tooth found in the Bulalacao Peninsula among Miocene rocks was identified by A. N. Krystafovich as *Carcharodon arnoldi* Jordan. The tooth of a large shark is the earliest record of sharks in the Philippines. It is found in beds in the Philippines older than those in which comparable sharks' teeth have been found in Japan and the Western United States.

It should be noted that the percentage of surviving species in the Vigo fauna is much higher than the comparable percentage applicable to Europe. This can be explained by the archipelagic

and tropical conditions that have prevailed in the Philippines since the Tertiary. A great variety of habitat could provide shelter to species migrating from the higher latitudes that progressively became colder.

The Lyellian percentages of Neogene molluscs in Panay show a different pattern. The study by Tsugio Shuto in 1969 covered five assemblages ranging from the Mio-Pliocene to the Plio-Pleistocene. A total of 136 gastropods were described systematically in the study and at least 20 bivalve species were found. The Lyellian percentages determined by Shuto are as follows:

Locality	*Percentage Living*			*Age*
	Gastropod	*Bivalve*	*Total*	
SKGS — 71	56.7	57.1	56.8	Early Late Pliocene
SKGS — 72	50.0	0	36.3	Pliocene
SKGS — 73	57.5	76.9	63.0	Late Pliocene
SKGS — 74	31.4	50.0	33.7	Late Miocene
SKGS — 75	44.4	—	44.4	Mio-Pliocene

The sample sizes of localities SKGS-72 and 75 are insufficient for reliable age determination and interpretation of the ecological conditions. Except for the ratio of surviving bivalves in SKGS-73, the percentages of surviving species in Panay are significantly lower than that determined in the Bondoc Peninsula. It would therefore be important to restudy the Vigo group in Bondoc in view of this discrepancy.

Shuto also interpreted the ecological conditions prevailing in the Upper Miocene as deriving from the Pliocene basin of deposition in Panay. SKGS-71 was underlain by a sandy silt and a silty sand bottom inhabited mostly by species abundant at 10 to 30 meters depth. Exotic elements from shallower waters were deposited by turbidity currents whose velocity was less than 40 cm/sec. During periods of weak current, the velocity went down to less than 1 cm/sec. In contrast to this locality, SKGS-73 is underlain by a fine sandy bottom. Species that are most common inhabit areas with 10 to 20 meters of water depth. A few brackish species are found but the waters were probably 20 meters deep. During weak phases of the current, the velocity was 0.5 to 2.3 cm/second while during strong-current periods, velocities of a few tens cm/sec. were reached. The fossils in SKGS-74 have populations that commonly inhabit depths of

20 to 30 meters and 200 to 300 meters. The environment is interpreted to be deeper than the other two localities, perhaps in the deep shelf edge where the environment of the two fossil populations may overlap.

The occurrence of intermittently strong currents suggests that tens of millions of years ago, the Philippine archipelago was also buffeted by storms and shaken by earthquakes. These triggered the release of turbidity currents which during the stronger phases attained the velocities estimated by Shuto.

In addition to the environments inferred in the study of the Bondoc Peninsula and Panay, the Philippines during the Mid-Cenozoic offered a variety of environments not greatly different from the Philippines of today. However, in vast areas submerged under the sea and adjacent to the volcanic islands of the Neogene, reefs like those found today developed. Reefs today provide the habitat for the greatest variety of life on earth. This was presumably true also during the Neogene. Today's reefs are of interest not only to marine biologists but also to other scientists interested in the interplay of the flora and fauna inhabiting the reef and their response to pollution. Reefs of the past were sources of hydrocarbons for petroleum and they may now be reservoirs for oil and gas. Studies of modern and ancient reefs are therefore valuable in oil exploration. The commercial discoveries of petroleum in the offshore areas of Western Palawan are in fact reservoirs developed in Lower Miocene reefs.

An idealized model of the variety of environments in Miocene reefs in the central portion of the Philippines (in the Visayas) is reconstructed by Albert V. Carozzi, Milagros V. Reyes and Victoriano P. Ocampo who studied thousands of rock samples. Their model is shown in plates showing the zonation of Miocene reefs in the Visayas where a varied "sedimentary landscape" may be noted. Fringing the land areas are the estuaries, mangrove swamp, tidal flats and beaches. In this environment, debris from the weathering and erosion of the volcanic islands predominates over carbonates. These clastic materials are associated with remains of echinoids, gastropods, thin pelecypods, fecal pellets of worms, sponge epicules, ostracods, some rare Miliolids, Rotalids, Texturarids and plant material. The shoreface environment represents the transition between clastic and carbonate deposition. In the seaward direction, the lagoonal environment follows. This

environment is the most complex of those found in this model. Foraminiferal and gastropod banks are found with finger corals and patch reefs. This environment intertongues with the back-reef environment found behind the main coral-red algal reef barrier. The latter is a complex framework of corals, algae, bryozoans and foraminifera. Its zone facing the open sea is broken by waves to form the fore-reef talus environment. In places, tidal channels cut across the main reef barrier and through these channels, the fore-reef apron environment is connected with the back-reef environment. This zone is where deeper water pinnacles develop. The rapid vertical growth of pinnacle reefs allows them to keep pace with basin subsidence. The deeper waters stretching seaward constitute the open marine environment.

The model shows the variety of environments available to species migrating from other areas. The sedimentary landscape is complex because of the tectonic instability of the Philippines during the Cenozoic. Rock types show considerable variation laterally, making stratigraphic correlation difficult. Basin subsidence during the Miocene favored vertical buildup of reefs near the edges of the basin.

This model is not unique to the Philippines. Pleistocene reefs in Barbados show similar features. However, instead of island arcs as the source of sediments, the reefs in Barbados are adjacent to an older carbonate terrain.

Land areas in the Neogene tropics presumably supported forests which have a complex and stable ecology. Remains of a dipterocarp forest are found in the Pliocene rocks of Sagada, Mt. Province. Warren Dupré Smith in 1915 collected plant imprints which Elmer D. Merrill identified. The living forms included *Shorea polysperma* (tangile), *Shorea guiso* (guijo), *Anisoptera thurifera* (palosapis), *Callophyllum blancoi* (palomaria) and *Diplodiscus paniculatus* (balobo). The maximum development of the dipterocarp forest takes place below 700 meters. The remains were found at 1,500 meters elevation in an area occupied by a mid-mountain pine forest. The fossils bear witness to an uplift of several hundred meters since the Pliocene.

In Marianas, *Agatis* cones are found in lignite beds of the Airai formation which is dated as either uppermost Pliocene or lowest Pleistocene. *Agatis*, known locally as *almaciga*, is found

in the Philippines at 200 meters elevation. The Alrai beds are found in the lowlands and hence their occurrence has been used to infer that they were transported from higher elevations before being deposited in the lignite beds of Babelthuap Island in the Palau Group.

Pollen recovered from the Middle Miocene to Pliocene rocks in offshore areas in northwest Palawan include the following:

Laevigatosporites spp. (dominant)
Zonocostites ramonae
Calophyllum — known locally as *palomaria*
Casuarina — the genus agoho or iron tree
Retitricolpites (cf. *Shorea*)
Dicolpopollis sp. — related to Calamus, the genus of *uay* or rattan

Psilatricolpites
Acrostichum — the genus of a fern known locally as *pakung laut* or sea fern
Davallia — also a fern

In older rocks ranging from the Upper Eocene to Oligocene, the following pollen are found in the southwestern Philippines:

Laevigatosporites sp.
Zonocostites ramonae
Dacrydium — a southern hemisphere gymnosperm
Florschuetzia trilobata
Avicennia — genus of apiapi, a mangrove plant
Pandaniidites
D. cf. *elegans*
Pteris spp. — genus of the common fern
Acrostichum
Cyathea type — Cyathea is a tree fern
Lycopodium cernuum — a club moss

In the Sulu Sea, *Florschuetzia, levipoli,* which are pollen derived from the mangrove plant *pagatpat* (*Sonneratia caseolaris*), first appeared during the Miocene. Mangrove swamps in which this plant flourished are now covered by the Sulu Sea. Other mangrove species associated with *pagatpat* during the Miocene in the Sulu Sea are:

Lower Miocene: *Florschuetzia trilobata, F. semilobata, Dicolpopollis* sp. *Retistephanicolpites williamsi* (pollen thought to be derived from the species *Ctenolophon parvifolius*), *Striatricolpites catatumbus, Spinozonocolpites echinatus.*

Late Middle Miocene: *Florschuetzia trilobata, F. meridionalis, Spinozonocolpites echinatus, Discoidites borneensis.*

Upper Miocene: *Florschuetzia meridionalis, Spinozonocolpites echinatus, Discoidites borneensis, Zonocostites ramonae.*

These plants come from the back mangrove environment.

In the Pliocene, spores of the fern *Stenochlaena laurifolia* appear in sediments of Borneo and the Sunda Shelf and this disappears during the Quaternary. Another fern, belonging to the same genus, *Stenochlaena areolaris,* first occurs in sediments of the Lower Miocene and disappears during the Pliocene. These are related to the fern known locally as *diliman* (*Stenochlaena palustris*). All three ferns are still found in the Philippines and New Guinea today. It will be recalled that *Verrucatosporites usmensis,* the spores of *diliman,* are found in Paleogene sediments in the Philippines.

Some of the pollen found in the Miocene-Pliocene are represented in the plant remains found by Smith in Sagada. Others like *Casuarina, Acrostichum, Dicolpopollis* and *Avicennia* are inhabitants of nearshore environments like beach forests and mangroves. The mangrove environment is also found in Borneo and presumably other areas in Southeast Asia. The floral zonation established in the Paleogene and found even today must have persisted in the Neogene. In Europe, the tropical Indo-Malesian flora predominant in the Paleogene are driven southwards as the climate became colder. North Africa and Southwest Asia became drier during the Pliocene, thereby stimulating the spread of desert flora.

The distribution of plants and the presence of Asian temperate flora in Southeast Asia also indicate land connections linking Southeast Asia and the Mainland during the Neogene. According to Dr. Robert Morley in 1977:

> "An important pollen source in Southeast Asia are montane areas. Many montane taxa are wind pollinated and produce very large quantities of pollen which may disperse over a wide area. Muller (1966, 1972) recorded the common occurrences of a number of pollen types exhibiting Asian temperate affinities from the Oligo-Miocene of Borneo. These include *Abies, Alnus, Ephedra, Picea, Pinus* and *Tsuga*, none of which could have developed in Southeast Asia without the existence of direct land connection with Continental Asia. These pollen types are very common in the Oligocene and Lower Miocene of the Sunda Shelf, and suggest that montane areas of moderate elevation were formerly much more extensive in the surrounding region than at present. The occurrence of former montane links between Southeast Asia and the Asian mainland has been suggested previously from biogeographical reasoning by van Steenis."

Land connections between the Philippines and Asian mainland during Early Tertiary times had also been suggested by Dickerson in 1924 and 1928.

Conifers existed in Borneo and Indonesia during the Neogene. Jan Muller in 1973 found pine pollen in sediments up to the Pliocene. This indicates that the climate and topography of the islands to the southwest of the Philippines were suitable for temperate flora perhaps similar to the environment and flora now persisting in the Central Cordillera of Northern Luzon. Changes occurring after the Neogene resulted in the extinction of the temperate flora.

There are therefore a great variety of environments and diverse life forms in the Philippines during the Neogene. Such diversity may have existed prior to this period of time but older rocks are not yet as extensively studied as rocks in the Neogene which are being explored and developed for coal, oil and gas. Many of the marine shells which are found in Lower Miocene rocks are still found today. Occurrences of oysters, *Mytilus* or mussels known locally as *tahong*, cowries and ark shells are

reported by various paleontologists and geologists. Even the sharks preyed on the abundant life thriving in Philippine waters. Worms, corals, algae, foraminifera, sea urchins, bryozoa and presumably crabs and a plethora of fishes were found in what was called by earlier writers as the Vigo Sea. On land, mangrove swamps fringed the beaches and tidal flats and farther inland, tropical forests provided shelter for birds and other animals. Storms swept down some trees and triggered turbidity currents. These are recorded by remains of petrified wood in beach environments and in the presence of "exotic" elements in various marine environments.

The terrestial organisms covered land which resulted from the orogeny and uplift during the Oligocene. This event exposed older rocks and removed these by weathering and erosion. Mountains were formed. Continued deformation of the crust resulted in eventual subsidence of a large portion of the Philippine Archipelago and the invasion of the land by the sea. More than half of the land area of the Philippines became covered by the Neogene sea and the sedimentary deposits formed during that time now underlie about 55% of the land area of this country. Taiwan in the north and the Brunei-Sabah area to the southwest have also been affected by the Miocene transgression of the sea.

An example of the progressive encroachment or transgression of the sea on the pre-Miocene land surface can be seen in the paleogeographic map constructed by L. B. Christian in 1966 and reproduced in the plate labelled as a worm's-eye view map. As subsidence of the Cagayan Valley basin increased, areas covered by younger marine rocks became progressively larger. The edge of the sea crept eastwards toward the Sierra Madre Range which presumably was land during the Neogene. During the Early Miocene, the deepest part of the basin was near the edge of the Central Cordillera of today. However, the middle of the basin shifted eastward. The eastward movement of the axis of the basin is illustrated in the plate that follows the worm's-eye view map. Deposition of sedimentary rocks from the start of the Miocene resulted in a thickness of about 12 kilometers of the sedimentary rocks. Without this sedimentary filling, the Cagayan Valley would today be a deep sea trench.

Subsidence of 12 kilometers over 25 million years would give an average rate of subsidence of about 0.5 mm/year, a rate

which appears to be infinitesimally slow but actually a rate of that velocity is rapid for geological processes. If Manila were subsiding at that rate, the subsidence would amount to 30 centimeters or almost one foot within a span of 600 years. And within a historic span of 3000 years, the subsidence would total 1.5 meters.

The estimated rate of subsidence is also about the same as the rate of uplift of geologically active regions. In order to supply sediments that will fill the basin at a rate which will keep pace with the subsidence, the area from which sediments come should also be uplifted at about the same rate to maintain a supply of clastic debris and to remain topographically high. The amount of uplift of the Pliocene dipterocarp forest which has resulted in its present elevation at Sagada would give a rate having the same order of magnitude as that estimated for the subsidence.

With the migration of the basin axis and the filling of the Cagayan Valley basin through time, a vertical and lateral shift of the sedimentary landscape also took place. This is shown in the idealized cross-section showing facies adapted from Noe Caagusan's study presented in 1977. The deep basin environment grades laterally to the neritic environment and vertically to a fluvio-marine environment. The neritic environment in the east is later transformed to a lagoonal environment. Towards the Middle Pleistocene, the latest deformation evened up the Pliocene and younger rocks, thereby producing the configuration shown in the topmost section of the plate showing the evolution of the Cagayan Valley.

The Mid-Pleistocene deformation accentuated the northsouth trend of movement in the Cagayan Valley basin. During the early part of the Neogene, however, a northeast trend existed, moving along the trend of Palawan and other parts of the Philippine archipelago south of the Philippine fault. The southwest portion of the basin covered Benguet and may therefore have been connected with Central Valley basin which extends from Manila to Ilocos Norte.

The marine transgression over the Central Cordillera is recorded in the marine sediments found in various parts of the

Cordillera. This includes the Miocene limestone caverns in Sagada and other areas. The evolution of this magnificent mountain range as it rose from the sea can best be appreciated from this brief and clear summary of Dr. Arsenio Gonzales who described the geologic history of the Lepanto Mine and its vicinity:

"1. A thick sequence of basalt and andesite flows was extruded on a basement that is not exposed. In the later stages of this volcanic activity, fragmental components were intercalated with the flow rocks. No definite date can be assigned to this volcanic activity, and it may have occurred either in Late Mesozoic or Early Tertiary time.

2. After folding of the previously deposited rocks, and truncation by erosion, the Balili sediments were deposited during Oligocene time. The depositional period closed with the laying down of the limestone unit of the Balili sediments in Late Oligocene or Early Miocene time.

3. A period of mild deformation occurred in which a broad anticlinal arch was formed. A North-trending zone of normal faults formed near the arial region of the arch, probably as a result of the release of the folding stress.

4. This folding was followed by the emplacement of the Bagon intrusive. The metamorphism of the Lepanto metavolcanic rock is probably a result of this intrusion.

5. During most of the Middle and Late Miocene, the area was subjected to rapid erosion. Down-cutting was apparently facilitated by the fractures along the crest of the previously formed arch. By Late Miocene time, the region was probably reduced to a gently rolling or even a flat area.

6. During the Late Miocene, and probably up to the Early Pliocene, the region was a scene of intense volcanic activity. Dacitic pyroclastics and lavas were extruded from volcanic centers in the region.

7. In the later stages of the volcanic activity, hydrothermal solutions invaded the area. . . . Later, the solutions became richer in metals, and ore deposits were formed in fractured parts of the previously silicified zones.

8. The latest chapter in the history of the area is probably characterized by a broad uplift. The streams began to dissect rapidly, producing the present youthful topography. . . ."

During the Early Miocene, a volcanic complex existed along the area now known as the Central Knot. The alkalic composition of the complex is unusual for the Philippine setting. The volcanic centers in Isabela and Nueva Vizcaya are now marked by outcrops syenite and monzonite. These igneous rocks of deep-seated origin are rich in potash feldspar unlike most other Philippine plutonic rocks which do not contain this type of mineral in abundance. In Cordon, Isabela, the alkali-rich volcanic rock tinguaite along with other igneous rocks of unusual composition are found with the syenite and monzonite. An uncommon volcanic mineral, pseudoleucite, is found in the tinguaite porphyry. A few kilometers away, analcite basalt or monchiquite is found along Magat River where a dam is being constructed. Welded tuffs from the damsite are coeval with the Cordon intrusives, both rocks being 22 million years old (Early Miocene) by K-Ar dating. Copper and gold are associated with the alkalic rocks in Isabela and Nueva Vizcaya.

The Central Valley of Luzon was submerged during this period. The Sierra Madre Range in the east supplied sediments to the basin which today exceeds six kilometers in depth along the deep portions. The edge of the basin has shallow waters characteristic of a tidal milieu. In the Montalban area, the base of the Late Oligocene Montalban formation consists of a conglomerate containing well-rounded andesitic and basaltic pebbles from the underlying Sierra Madre basement. This grades to a sequence of limestones, then clastics, which is characteristic of an oscillating environment. Farther east, tuffs overlie the sequence thereby indicating that volcanism also took place during that time in this area. Foraminifera from Nueva Ecija and Bulacan indicate that the Early Miocene rocks in these areas were deposited in moderately deep waters of the open sea. These are succeeded by shallow water fauna which sprouted towards the Middle Miocene. A renewal of the subsidence occurred during the Middle Miocene. Towards the end of the Miocene, diastrophism resulted in the erosion of Miocene strata in some areas. Renewed

transgression of the sea during the Pliocene deposited a thick blanket of sediments over the Miocene rocks.

In the West, it will be recalled that the Aksitero formation, belonging to the Paleogene, is a deep water deposit. This is succeeded by a neritic environment with tidal influences as indicated by the limestone lenses in the Moriones formation of Tarlac. These lenses are interpreted to be ancient patch reefs. The tidal influences persisted through the early Late Miocene. During this time, mountain building events brought in a fresh supply of coarse clastic material. The Pliocene in the western part again shows a tidal environment.

The Central Valley can therefore be interpreted as a trough related to a volcanic arc in the east. The Zambales Range in the west developed into another volcanic arc during the Late Miocene and thus became a source of volcanoclastic material. The stages leading to the development of the Central Valley basin are summarized in a plate showing the geologic revolution of the Central Valley following the interpretation of BEICIP, a French petroleum institute.

Lower Miocene rocks belonging to the nearshore environment rest on Cretaceous and older rocks along the Tayabas Isthmus. The sediments come from the north, with the shoreline close to the present shore. However, the seaward side during the Early Miocene is to the south which is land today, whereas the land area is to the north which is now marine. Later in the Early Miocene, the source shifted to the west and the southwest. This shift may be correlated with the emergence of the Sierra Madre.

The southern part of the Central Valley Basin is now underlain by Pleistocene and recent volcanics. During the Neogene, the area was marine and hence the basin, although now structurally distinct from the basins in the south, was connected to basins in the south. The island of Marinduque, however, was a volcanic center during most of the Miocene. Volcanic islands were also distributed along the Visayas.

The Bicol Peninsula was also invaded by the sea at the start of the Neogene. Its location and also the location of the islands of Samar, Catanduanes and Eastern Leyte, all being east of the Philippine fault, must have been south of its present position.

This would, in effect, place it in juxtaposition with the Visayan sea. Studies on the past environments of rocks in the Bicol Peninsula and Eastern Visayas give rise to the map labelled as the Miocene geography of the Bicol Peninsula which shows how the area looked during the Miocene. The map shows reefs, beaches, swamps and islands. Catanduanes is mostly land while only the middle portion of the Bicol Peninsula is mostly terrestrial. It may be noted that the shape of the land areas then was different from the present-day shape. The sea and nearshore environments cover most of the Bicol Peninsula. Before the Miocene, however, a large land mass can be traced, including offshore areas now covered by the Pacific Ocean. Land also extended into what are now offshore areas in the Visayan Sea, Sulu Sea and Palawan. In the Tembungo oil field, N. Borneo, unconformities in the Lower Miocene, Middle Miocene and Lower Pliocene are found in the offshore field. These unconformities, indicating erosional events, are also found in Palawan. During these periods, therefore, land connections existed between islands of the Philippines and between the Philippines and neighboring areas. The outline of this land in the Bicol is shown in the plate just discussed.

The western edge of this landmass along Lamon Bay could perhaps be correlated with the edge of the Visayan Shelf and the Sibuyan Sea. This edge is displaced by the Philippine fault by about 100 kilometers, indicating that there had been this amount of movement since the Miocene. This amount is consistent with displacement of gravity anomalies in Northern and Central Luzon. A displacement of this amount would align the Central Cordillera of Luzon with the Southern Sierra Madre range. The southward extension of the Cagayan Valley Basin would then fall in the Lamon Bay-Bondoc Peninsula portion of Southern Luzon.

The varied environments in the Visayas have already been discussed. Among the Visayan Islands, Cebu is one province which has a long history and a complex structure. Parts of Cebu and Bohol remained terrestrial during the Early Miocene transgression by the sea. Swampy areas formed coal deposits. Offshore areas were sites of thick sedimentary accumulations reaching eight kilometers in thickness. The island of Panay was also traversed by the sea with the eastern side shallower

than the western side. A cross-section of the Panay Basin is shown in the plates. The rocks show frequent reworking and mixing of shallow and deep faunal elements.

Neogene sedimentary rocks cover Northwest Leyte. The Upper Oligocene (?) to Lower Miocene Taog formation is a clastic unit with occasional layers of coal. This nearshore unit is overlain unconformably by the Middle Miocene Tagconot formation which consists predominantly of mudstones. The unconformity indicates that for a while Northwest Leyte was emergent during the Miocene. The prominent ridges in the landscape today consist of the reefal Calubian Formation which overlies the Tagconot. During the Late Miocene, a shale-sandstone association with tuffaceous and bentonitic lenses was deposited. This unit, known as the Bata Shale, contains the Balite tar sands, an indication that hydrocarbons were generated in the area. Studies on the distributions of carbon isotopes and hydrocarbons of the Neogene rocks, oil seeps and tar in Leyte, done by R. Reyes, Jr. in 1979, show that hydrocarbons, oil and asphalt were derived from organic material incorporated in the Lower Miocene Taog formation.

In the Visayas, the Neogene is characterized by transgression and the development of small bioherms during the Early Miocene. The greatest development of reefs took place during the Middle and Late Miocene. These are separated by shallow marine clastics that are interbedded with acidic volcanics and tuffs. Thus, igneous activity can be noted during the latter part of the Miocene. Unconformities mark periods of emergence. In Samar, Lower Miocene rocks are strongly folded whereas the unconformably overlying Upper Miocene rocks have gentle dips. However, a widespread submergence took place during the Pliocene with the deposition of the Carcar Limestone and its other equivalent sedimentary rocks.

The submergence during the Neogene also affected Mindanao where thick sequences were deposited in the Davao-Agusan trough and the Cotabato Basin. A cross-section through Mindanao is shown among the plates.

The eastern side of the Davao-Agusan trough is bounded by the Philippine Fault in the east. In general, finer clastics are found in the east while coarser clastics are found west of the

trough. The sedimentary rocks, ranging in age from Eocene to Pleistocene, attain a thickness of more than four kilometers. The Eocene limestone in the trough is unconformably overlain by Lower to Middle Miocene clastics and limestone. These are covered by Upper Miocene to Pliocene marine sediments.

The Cotabato Basin contains more than 8.6 kilometers of sedimentary rocks ranging in age from Late Oligocene to Pleistocene. These rest on a basement consisting of volcanics, schist and metasediments. The oldest unit deposited during Late Oligocene to Early Miocene contains conglomerate, sandstone and limestone. During the Early Miocene, conglomerate and graywackes interbedded with shale were deposited. Two limestone units contemporaneous with the clastics were deposited in the northern part and in the south central part. By Middle Miocene time nearshore and terrestrial sedimentary rocks were deposited in the northern part of the basin whereas offshore, marine sediments were deposited in the south central portion of the basin. Late Miocene sedimentation was found to become increasingly terrestrial in the south. After a period of erosion, a return to shallow marine deposition took place during the Pliocene. These were in turn overlain by fluviatile and lacustrine deposits of Plio-Pleistocene age.

To the west, in Zamboanga, Early Miocene sedimentary rocks accumulated by uplift and sedimentary filling resulted in the transformation of some parts of the marine environment into swamps where coal formed. During Middle or Late Miocene time, folding and uplift exposed the area to prolonged erosion. Volcanism during Late Miocene and Early Pliocene covered the older rocks with basalts and tuffs.

The Sulu Archipelago is covered mainly by young volcanics and limestone. Otherwise, metamorphic and igneous rocks are exposed. However, there is a Miocene conglomerate in Bongao Island. Neogene sediments are more extensive in the Sulu Sea which could have been the northeastern extension of Northwest Borneo's geosyncline. One offshore well drilled down to 4601 meters yielded sediments from Early Miocene to Pleistocene age. Another well encountered coal beds beyond 305 m. from the sea bottom. Hence, in the past, parts of the Sulu Sea were near shore or even linked to the land and there has been a subsidence exceeding 300 meters since the Late Miocene and Pliocene.

Offshore drilling for oil in Western Palawan has also yielded evidence that land was exposed many kilometers away from the present shoreline and several hundred meters deep. This is marked by the unconformity between Middle Miocene rocks with Upper Miocene-Pliocene rocks. Southern Palawan is covered partly by Tertiary sediments but these are essentially absent in the north. Neogene sediments, however, have accumulated in offshore areas and these have proven to be an important source, as well as reservoir rocks, of oil and gas.

The northwestern Palawan Basin, where commercial discoveries of petroleum have been made, is separated from the western Palawan Basin by the north-south trending Ulugan Bay fault. During Oligo-Miocene time, the shelf edge had a northeast-southwest trend, deepening to the northwest. The basin was tilted to the west during Late Oligocene time, making the shelf edge prominent. Reefs formed on topographic highs along a trend following the edge. The development of patch, pinnacle, atoll, and bank-edge types on reef was encouraged by slow basin subsidence during Late Oligocene to Early Miocene time. Fine-grained sediments that consolidated into mudstones and clay stones were deposited contemporaneously along the sides of the reefs. Fine-grained clastics were supplied from the east and the northeast during the Early Miocene. The influx of these sediments terminated reef growth abruptly and buried the carbonate complex. During that time, the landmass to the east was elevated. A Middle Miocene uplift made the eastern portion of the basin emergent, thereby forming the Middle Miocene unconformity. Above this unconformity, shallow water deposits of the inner sublittoral to littoral environment consisting of conglomerate, sandstone, clay stone, and siltstone were found. The Middle to Upper Miocene clastics came from the east and the northeast. Transgression during the Pliocene and Pleistocene gave rise to carbonate deposits.

The sedimentary record for the Neogene therefore indicates that large areas of the Philippines were covered by the sea with occasional breaks in the record during the Middle Miocene and Upper Miocene owing to periods of uplift and mountain building. Another episode of widespread marine transgression occurred during Pliocene times.

While the sedimentary basin shows vast amounts of subsidence during the Neogene, equally large amounts of uplift took place in mountain belts adjacent to the basin where igneous rocks of intermediate composition (mostly diorite and quartz diorite, sometimes granodiorite) have been emplaced. Erosion has uncovered these magmatic rocks which cooled slowly under the onslaught of high pressures deep within the crust. These are now seen as intrusive masses ranging in size from small stocks, a few square kilometers in area, to batholithic masses that form the backbone of mountain ranges such as the Sierra Madre and the Central Cordillera of Luzon.

In the mountain ranges, these intrusives crop out even in elevations exceeding 2000 meters. These plutons intrude pre-Neogene submarine volcanics and sediments, such as in the vicinity of Mankayan, as described earlier in this chapter. Even if the sedimentary and volcanic cover were only three kilometers thick, the intermediate intrusives now cropping out at elevations exceeding two kilometers would indicate uplift of more than five kilometers. The adjacent basins, on the other hand, have subsided by several thousand meters. In the Cagayan Valley where 10 kilometers of subsidence can be measured, a total amount of vertical movement between the Central Cordillera area and the Cagayan Valley axis could be estimated to exceed 15,000 meters. Furthermore, the distance between the deepest part of the basin and the nearest batholith is less than 60 kilometers. An awesome deformation of the crust must have taken place in this narrow belt during the Neogene to produce this large vertical movement. A comparable deformation is probably taking place east of Mindanao where there is a trench with a depth close to 10,800 meters.

The Neogene plutonic intrusions affected large areas of the Philippine archipelago, namely the following belts: Central Cordillera, Sierra Madre, Marinduque, Tablas, Eastern Bohol, Eastern Mindanao, Mindanao Central Cordillera, Cotabato, and Zamboanga. The Northern Luzon belt has extensions into Taiwan, the Eastern Mindanao belt into Indonesia and the Zamboanga belt into Sabah. Neogene intrusives are also found in Japan and other areas of the circum-Pacific belt. Economically important mineral deposits are associated with these intrusives in the Philippines.

The Luzon Central Cordillera intrusive belt has a north-south trend extending from Pasaleng Bay, Ilocos Norte in the north to Baguio City in the south. The intrusive forms the backbone of the mountain range. Several types and ages of intrusives are recognized by various investigators. Around Baguio, Paul Schafer recognizes four intrusives starting from the Antamok diorite which he considers the oldest, probably even older than the pre-Middle Zigzag series of sedimentary rocks. The Virac granodiorite is considered younger than the Zigzag series. A third type, an augite diorite, occurs in the northern part of the Baguio Mineral District. The youngest intrusive is the Itogon quartz diorite which is also mapped as the Agno batholith. Hornblende diorite is the most common intrusive rock in the Baguio Mineral District. Pyroxene diorite, quartz diorite, and granodiorite are also present. To the north, Antonio Buangan and co-workers in 1968 recognized three types of intrusives, namely: a coarse-grained equigranular biotite diorite, an intermediate medium to coarse-grained, slightly porphyritic hornblende diorite, and a medium to fine-grained porphyritic and granular quartz diorite. The coarse biotite diorite is considered to be possibly equivalent to the Agno Batholith mapped by Schafer. In the vicinity of Mankayan, a coarse, acidic pluton is mapped as the Bagon intrusive. Dr. Arsenio Gonzales identified the rock as a trodhjemite.

The intrusives were probably emplaced between the Early to Middle Miocene. John Wolfe in 1973 reported ages of 14.8 and 9.4 million years for two samples of diorite collected south and southeast of Baguio City. The ages were determined by the K-Ar method.

Neogene intrusives are also found in the Caraballo Mountains. The plutons also crop out further south in the Sierra Madre range along the Quezon and Rizal boundary. These bodies in the southern extension of the Sierra Madre Range are smaller bodies and date back to the Middle Miocene.

West and south of the Central Valley of Luzon, there is another belt of Neogene intermediate intrusives. These could easily extend to the northeast trending belt in Marinduque. These diorites and quartz diorites usually form small bodies intruding metamorphosed volcanic and sedimentary rocks. In San Juan, Batangas, a quartz diorite sample is reported by Wolfe (1973) as 9.2 million years old (K-Ar method).

Farther south, a north-south trending Neogene belt crops out in Tablas, Romblon, Sibuyan Island, and in the Buruanga Peninsula, Panay. These quartz diorite plutons also crop out along the shore of Pandan, Antique.

Another belt of Neogene intrusives extends from the southern part of Leyte northwestwards into Bicol. Late Miocene to Pliocene quartz diorite with hornblende and biotite intrudes metamorphosed sandstones and shales in Inopacan, Leyte. In Barrio Talamban, Cebu City, a quartz diorite body is considered to be Middle Miocene or younger, inasmuch as it intrudes limestone which had been dated.

To the east, there is a long belt of Neogene intrusives that extends from Camarines Norte southward to Samar, Surigao del Sur, Agusan, Davao del Norte, and Davao Oriental. The trend of this belt is subparallel to the Philippine trench. In Camarines Norte, small dioritic bodies intruded the Eocene universal formation. Metamorphism of the calcareous horizon resulted in the deposition of iron deposits along with copper, molybdenum and uranium.

A cluster of large copper deposits is also found in the southern portion of this eastern belt. These deposits in Davao are also associated with gold mineralization. Eocene limestones have been intruded by quartz diorite and in a number of places there were iron deposits formed.

The ascent of these magmatic masses gave rise to mountain ranges which have since been levelled by the rapid erosion in this area. The eastern Cordillera formed a barrier between the Pacific Ocean and the waters of the ancient Philippine archipelago. This barrier is cited by Hiroshi Ujie and Tetsuro Samata in 1974 as the possible cause for the absence of several foraminiferal lineages in the Upper Miocene-Pliocene planktonic fauna of the Opol formation in Northern Mindanao, west of Cagayan de Oro City.

In the vicinity of Cagayan de Oro City, Middle Miocene diorite with quartz diorite and granodiorite phases intrude Eocene metavolcanic rocks of the Himalayan formation. In some places, the quartz diorite shows a banded appearance, which is termed gneissoid.

Neogene intrusives of intermediate composition are also found in other parts of Mindanao. A large outcrop of diorite, known as a batholith, underlies part of the Daguma Range in South Cotabato. In Kiamba, South Cotabato, volcanics older than the Neogene were intruded by Middle to Late Miocene quartz diorite. Elsewhere, such as in Bagumbayan, South Cotabato, the intrusives form steeply oriented tabular bodies known as *dikes*.

Another belt flanks the Philippines in the south. This is the Zamboanga belt in Zamboanga del Sur where diorite and quartz diorite intrude volcanic and sedimentary rocks. These intruded rocks could be as young as Early Miocene. In the east-central part of Zamboanga del Sur, a large, semi-circular diorite body that intrudes metamorphosed volcanic and sedimentary rocks is known as the Sibuguey diorite. This intrusive is placed within the Middle Miocene. Further west, diorite intrudes serpentinite on the islands of Tawi-Tawi. This body, in view of its alignment with the Zamboanga belt, could be part of the belt.

In the Middle to Upper Miocene, the bodies of dioritic intrusives now found at the surface bear witness to the widespread development of molten rocks. This generation of molten silicates, known as *magma*, could be related to the Middle Miocene mountain-building event which affected the whole archipelago, from the northeast in the Cagayan Valley to Palawan in the southwest. This event resulted in the retreat of the sea and the removal of previously deposited sedimentary rocks. This break in the record of rocks, as already pointed out, is said to be an *unconformity*.

Towards the end of this period of Philippine prehistory, there was a renewal of volcanic activity. Thus, in the Luzon Central Cordillera lava flows of dacitic composition may be found. Dacite and andesite are the volcanic equivalent of quartz diorite and diorite, respectively, which solidified at great depth. Volcanoes of dacite and andesite started to grow in the Late Pliocene and some of these are now inactive and dormant volcanic cones. In the Eastern Zambales range, radioactive dating shows that volcanism in the range started as far back as seven million years ago.

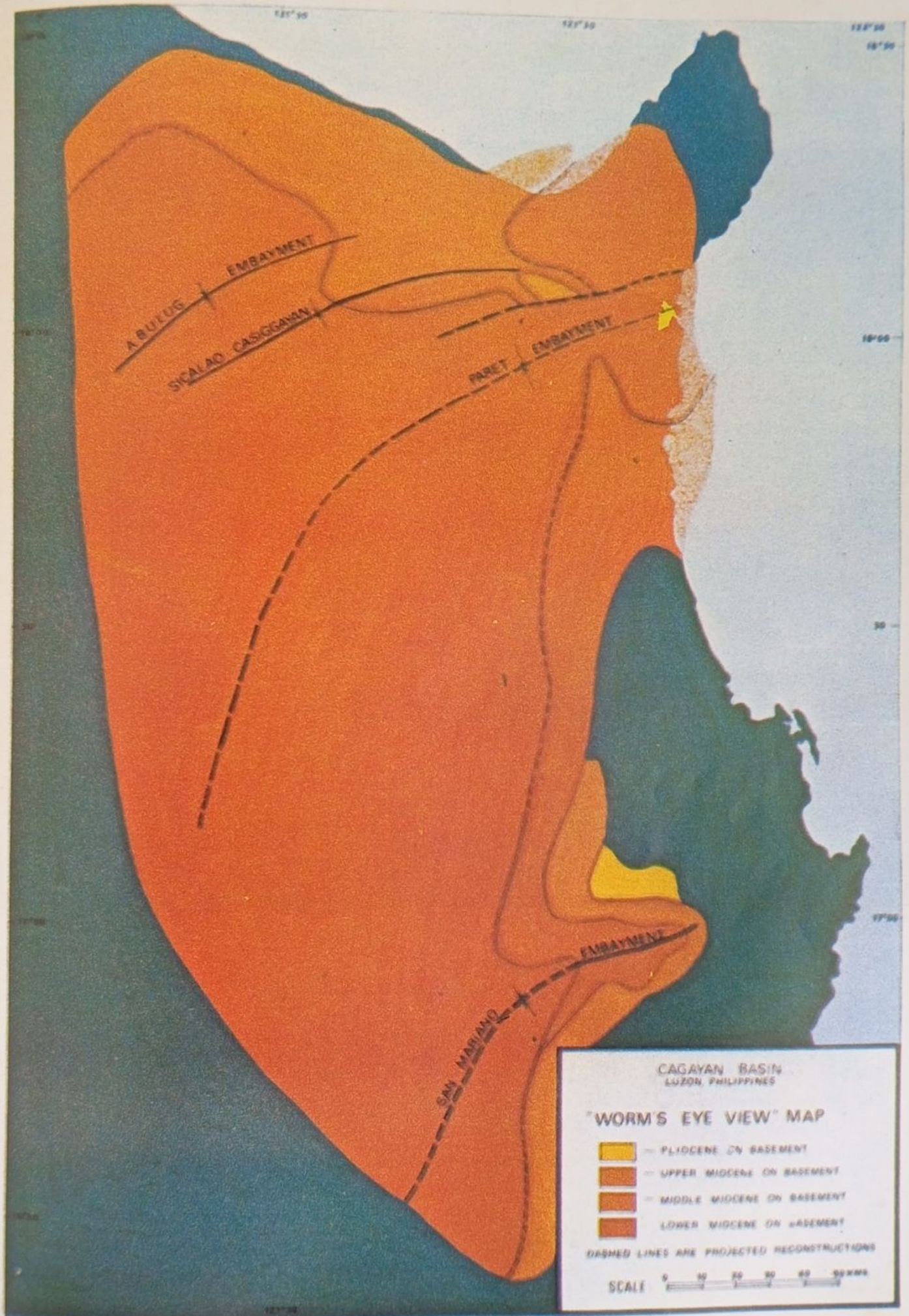
The stones and bones of the Neogene age therefore bear witness to numerous events that had taken place in the Philippines. They tell of the advance and retreat of seas, the growth

and destruction of mountain ranges, earthquakes and typhoons battering shores, reefs and swamps. The Philippine fault must have been active during this time, hence the archipelago must have suffered earthquakes even then. Some mountains and volcanoes which form the landscape today were absent but the growth and development of some of these features may have started during this time.

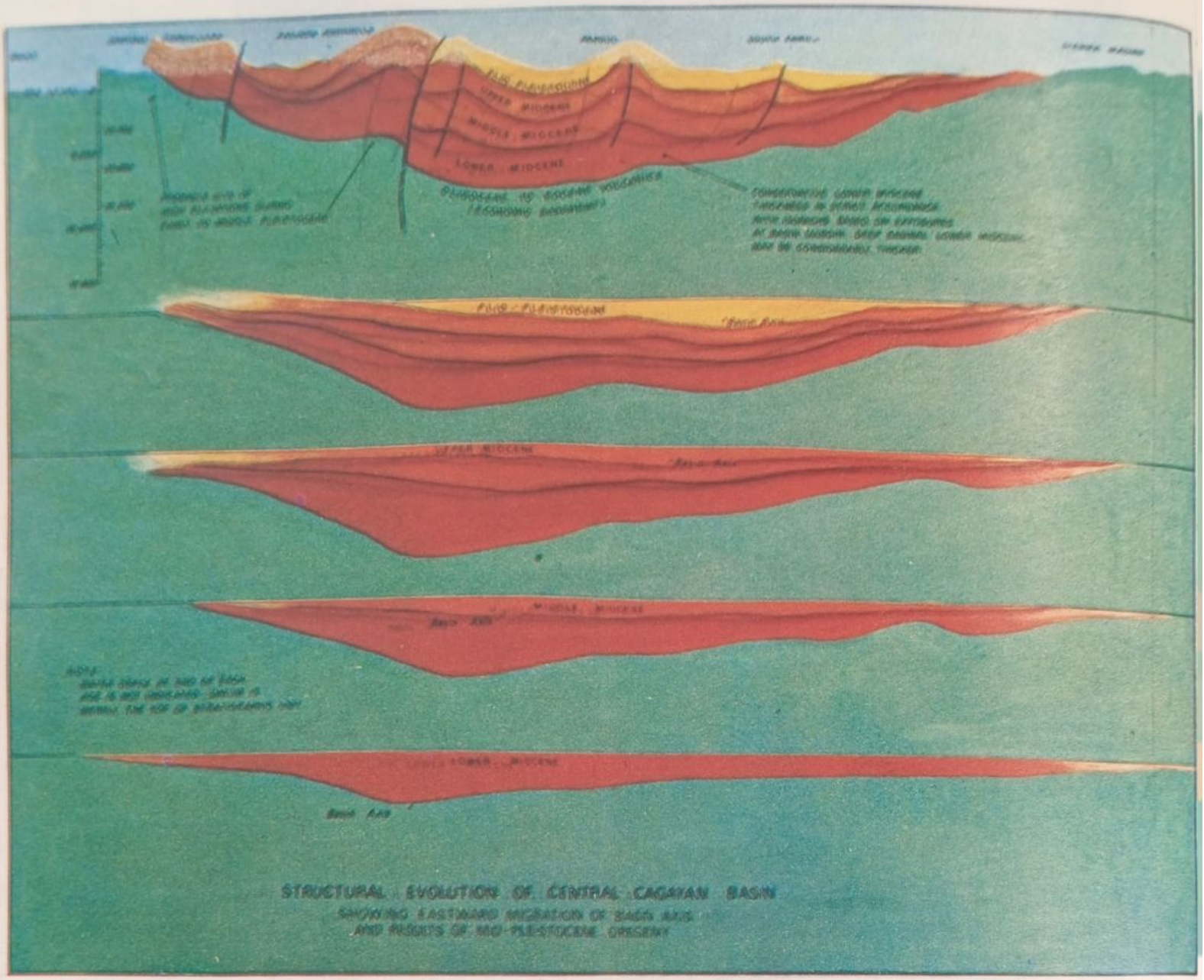
The Neogene is very important to the Philippines of today because of the abundance of earth resources that may be derived from rocks of this period. The diverse environments found during the Neogene led to the formation of deposits of energy and mineral resources which today benefit the people of the Philippines and the world.

As mentioned earlier, Lower Miocene rocks in Northwestern Palawan have formed reservoirs of oil and gas. Commercial deposits of oil had been discovered in Lower Miocene reefs that flourished in the warm, shallow seas of the Philippines. Among the oil-bearing reefs that have been discovered during the oil exploration efforts of the mid-70's were the reef complexes known as *Nido, Cadlao* and *Matinloc*. Oil from the Nido complex produced as much as 40,000 barrels of oil per day. The flow rates in the producing horizons of Nido and Cadlao had been measured as ranging from 1,400 to 9,880 barrels of oil per day and well logs measured reservoir porosities as coming up to 37%, with extensive secondary porosity in the form of fracture and openings known as vugs. The reservoirs in the reefs that have grown in excess of 600 meters have vertical closures that range from 180 to 300 meters. As of October 1978, recoverable oil from Northwest Palawan is conservatively estimated to be at least 50 million barrels. Toward the end of December 1979, cumulative oil production from the Nido complex came to about 8.5 million barrels of oil after production commenced in January 1979. The other field, Cadlao, is expected to reach early in 1981 a production rate of about 15,000 barrels of oil per day. Additional oil will be contributed by the adjacent Matinloc field, where active exploration is being undertaken while this volume is being written.

There are still many reefs in Western Palawan that have to be tested through drilling. It is therefore very likely that in the future much of the energy needs of the Philippines will



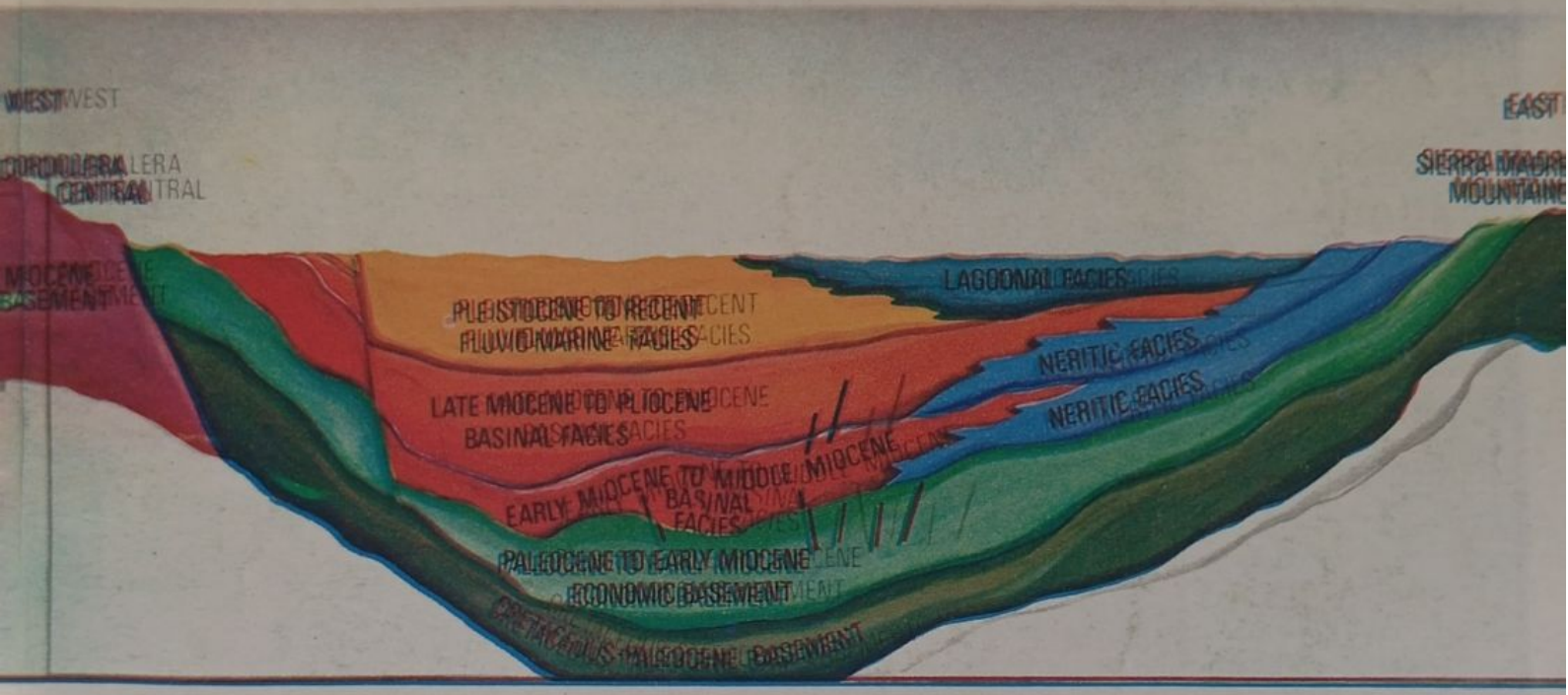
This map of the Cagayan Valley shows how the basin filled up with sediments. Outer margins were ancient margins of the basin which encrouched on land (basement areas).

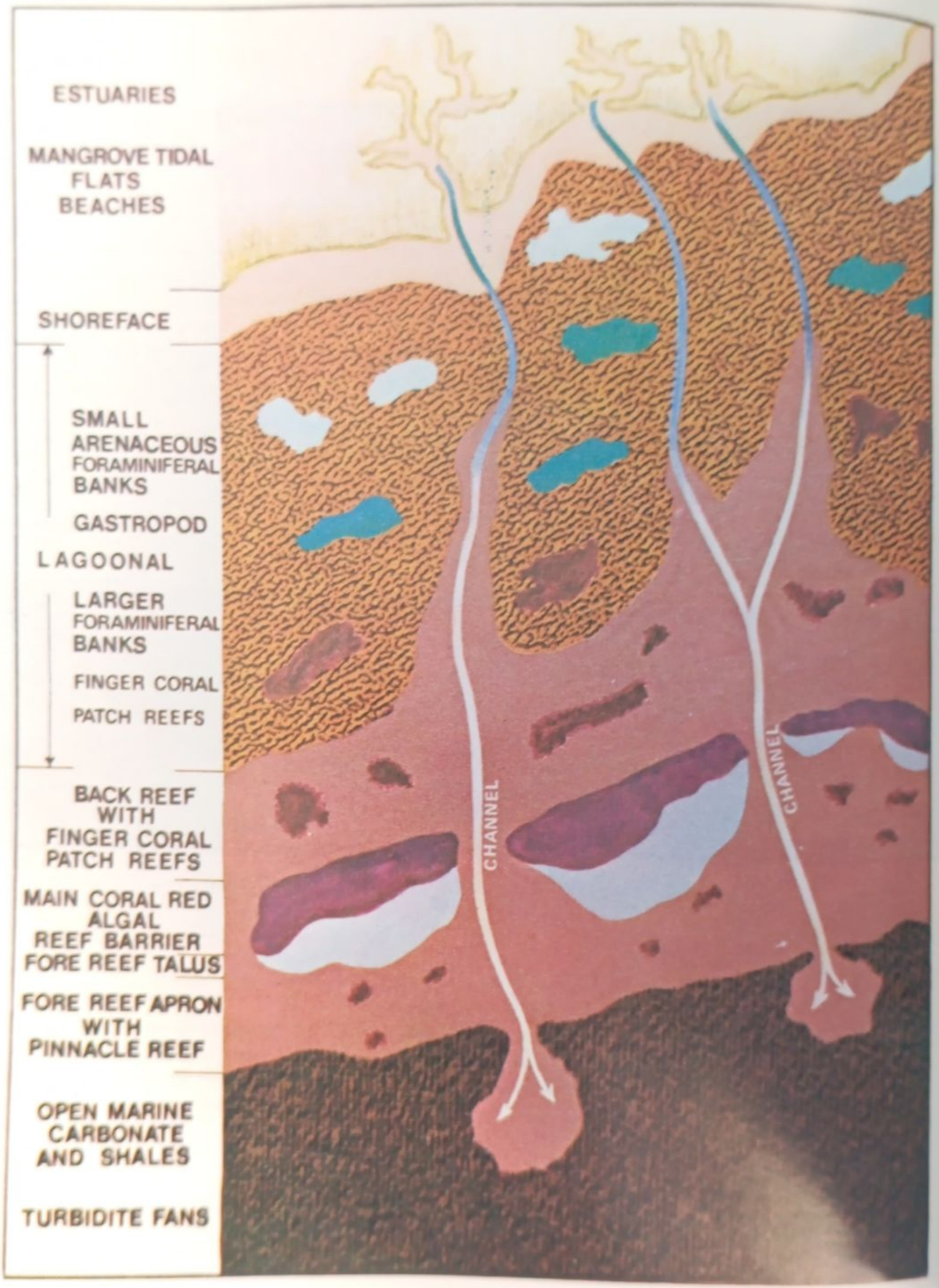


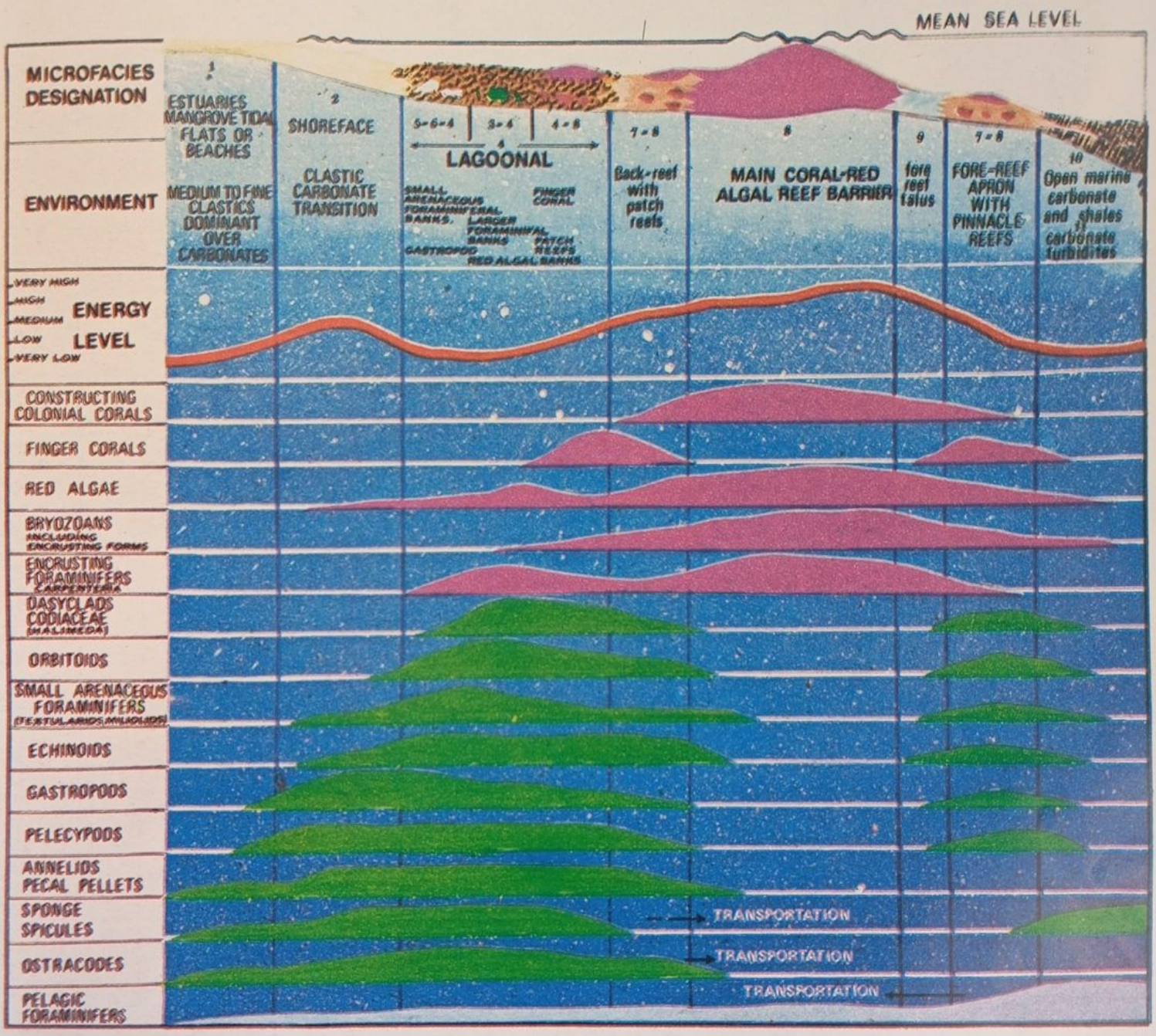
ABOVE:

The sequence of vertical sections above, starting from the bottom, shows how the Cagayan basin deepened and became filled up with sediments. The layers of sedimentary rocks were deformed during the Pleistocene resulting in warping of the layers known as folds. Continuity of the layers is broken by faults.

Schematic cross section of the Cagayan Valley Basin showing different environments of deposition (after Caagusan, 1977). Neutic facies represent marine environment, While Lagoonal facies consist of rocks deposited in Lagoons. Fluvio-Marine facies consist of rocks having characteristics gradational from marine to river deposits. The changes in depositional environments are related to distance from ancient land masses, the filling up of the basin and its conversion to the present day valley.

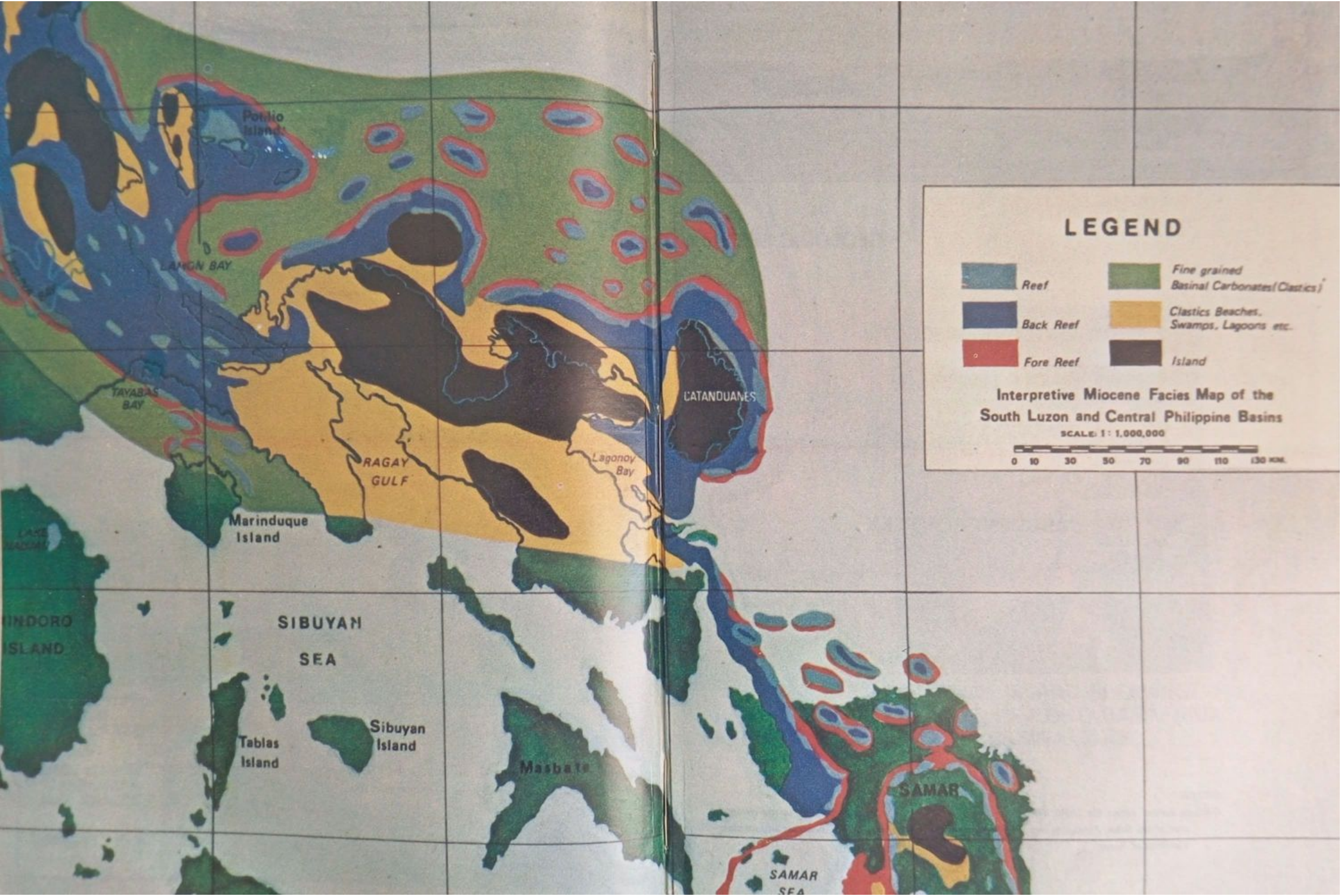


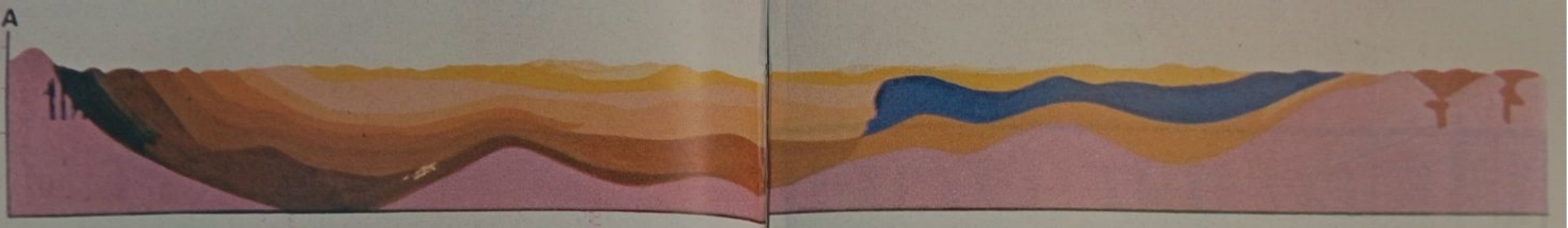

ESTUARIES
MANGROVE TIDAL FLATS BEACHES
SHOREFACE
SMALL ARENACEOUS FORAMINIFERAL BANKS
GASTROPOD
LAGOONAL
LARGER FORAMINIFERAL BANKS
FINGER CORAL
PATCH REEFS
BACK REEF WITH FINGER CORAL PATCH REEFS
MAIN CORAL RED ALGAL REEF BARRIER
FORE REEF TALUS
FORE REEF APRON WITH PINNACLE REEF
OPEN MARINE CARBONATE AND SHALES
TURBIDITE FANS
CHANNEL
CHANNEL



LEFT AND ABOVE:

Zoning of Miocene coral Reefs — Visayan Sea. These diagrams show the variation of environment and life across coral reefs about 20 million years ago.


Polillo Islands
LAMON BAY
TAYABAS BAY
CATANDUANES
RAGAY GULF
Lagonoy Bay
Marinduque Island
SIBUYAN SEA
Sibuyan Island
Tablas Island
Masbate
SAMAR
SAMAR SEA
LEGEND
Reef
Back Reef
Fore Reef
Fine grained Basinal Carbonates(Clastics)
Clastics Beaches, Swamps, Lagoons etc.
Island
Interpretive Miocene Facies Map of the South Luzon and Central Philippine Basins
SCALE 1 : 1,000,000
0 10 30 50 70 90 110 130 KM.



GEOLOGIC SECTION A-A' ACROSS ILOILO BASIN

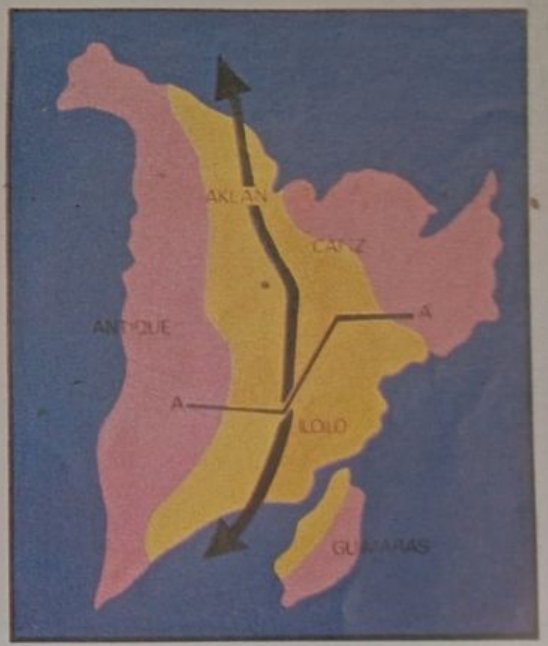
PLIOCENE - RECENT

DINGLE LIMESTONE

BAYUGO VOLCANICS

OLIGO - MIOCENE

BASEMENT COMPLEX

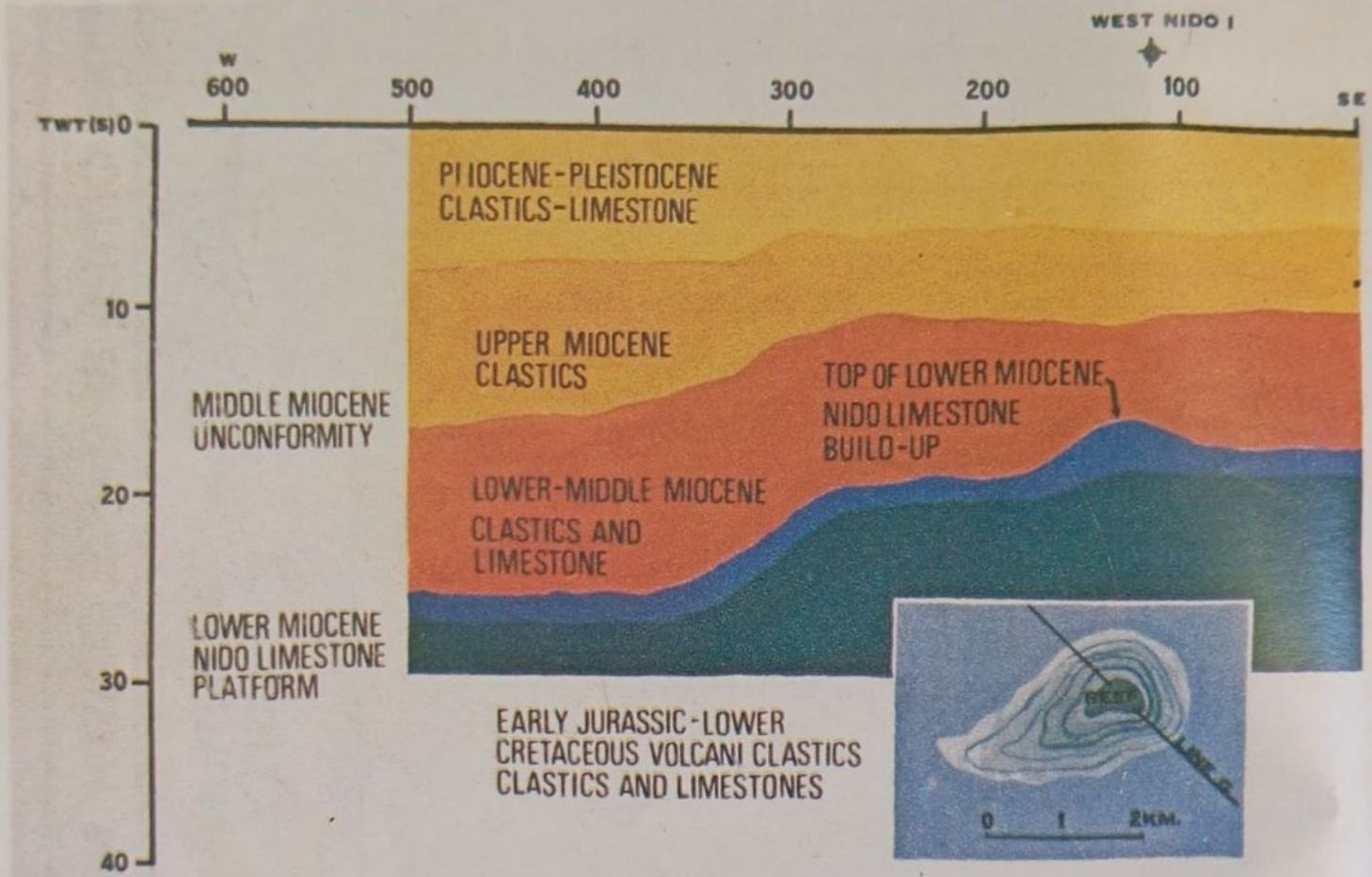


PANAY ISLAND SHOWING OUTLINE OF ILOILO BASIN AND BASINAL AXIS.

ABOVE:

Geologic section across the Iloilo Basin. The layers of sedimentary rocks are thicker in the western part of the basin. Paleogene and older basement rocks are exposed in the eastern and western highlands of Panay.

Well log and depositional environment of the oil bearing zone in south Nido - 1 well.



STRUCTURAL AND STRATIGRAPHIC SECTION for line - G,

Across the NIDO oil reservoir, PALAWAN (After Sali, 1978)

Structural and stratigraphic section for line G. across the Nido Oil reservoir, Palawan (after Sali, 1978). The blue layer represents limestone. Mounds of reefal material, formed close to the surface are now buried thousands of feet. These buried reefs form porous reservoirs for oil and gas.

be met by local production, not only by oil from Palawan but also from other sedimentary basins of the Philippines. In the Cagayan Valley, significant amounts of gas have been discovered in the Miocene Callao limestone. The Leyte tar sands had already been mentioned. Raymundo A. Reyes, Jr. in 1979 studied the asphalt and other surface oil and gas seeps of the Calubian Peninsula in Leyte and proved that these had affinities with the Lower Miocene Taog formation. Maturation studies of the organic carbon in the sedimentary rocks from the Leyte Basin showed that conditions required for the generation of petroleum had already been attained. Energy sufficiency of the Philippines is therefore an attainable dream, possibly within this generation.

Coal from Neogene swamps is also an important energy resource. Coal deposits are widespread in this country. However, the unstable conditions of the Philippine archipelago prevented the development of thick widespread deposits similar to those found in continental regions such as Australia, Europe, and North America. However, the Philippine coal deposits are barely tapped and explored. Their development and utilization will therefore supplement energy resources of the Philippines.

Some uranium was deposited with other minerals in the iron-copper-molybdenum deposit formed during the Miocene in Larap, Camarines Norte. Other uranium deposits, similar to those found in Indonesia and Japan, may yet be discovered in other areas of the Philippines.

The deposit in Larap is a contact metasomatic deposit, one which is formed by the migration of metals from an igneous rock that intrudes limestone. There are other areas that have similar geologic conditions and these areas may provide future sources of iron, gold and perhaps even tin and tungsten. Among these areas already known to have iron deposits are the Lammin Iron deposits in Piddig, Ilocos Norte, the Santa Ines Iron Deposits in Eastern Rizal, the Mati Iron Deposits in Davao, and the Sibuguey Iron District in Zamboanga. In Lammin, the iron deposits occur in metamorphosed volcanic and sedimentary rocks associated with recrystallized limestone. Fossils in the limestone indicate an Eocene age. The deposits had been ascribed to a genetic relation to diorite bodies by Juanito Fernandez in 1964.

Neogene intrusive rocks also carry important deposits of copper and gold. Several deposits of copper are found in Benguet, Marinduque, and Davao. In the Philex mine, Sukune Takenouchi found inclusions in the silica mineral, quartz, which contained ore minerals in addition to water and salt minerals. The salt content of the inclusions is estimated to be as much as 60 to 80 wt. %, which is rather high. The origin of such salty inclusions is not known but these inclusions are probably related to the origin of rich ore deposits such as those found in the Santo Tomas II orebody of Philex. This orebody has more than 160 million tons of copper ore containing more than 0.4% copper and significant amounts of gold and silver. The mill which processes the ore receives material containing 0.6 grams of gold per metric ton of ore. Hence, the mine is a gold producer in the Philippines.

A large production rate in copper is credited to the Marcopper Mine in Marinduque. The Black Mountain Mine and the Santo Niño in Benguet show a moderate rate of production. These deposits are large-tonnage, low-copper-grade (or content) bodies associated with quartz diorites. They are classified as porphyry copper deposits. Numerous prospects of this type are being developed in Luzon, Visayas and Mindanao.

Near Black Mountain, on the road to Baguio City, is a mine which produces gold, silver along with copper, lead, and zinc. The bodies containing these metals occur in a limestone which is intruded by quartz diorite. Another mine in Benguet which produces gold and silver with copper, arsenic and antimony is the mine in Mankayan operated by Lepanto Consolidated Mining Company. The history of the area was described earlier in this chapter. Unlike the porphyry copper deposits, the Lepanto ore deposit is related to volcanic activity. The mine was reported by the Spanish in 1833. Between 1864 and 1874, the mine produced 24,211.5 quintals of copper, or an average of 2,240.45 quintals per year.

The mine is important in the world of minerology because it is the source of the mineral described by Carl Zerrenner in 1869 as *luzonite,* named after the island of Luzon. Luzonite is a copper arsenic sulfide. It is found also in Taiwan, Japan, in Butte, Montana, and Cerro de Pasco, Peru. These deposits are grouped by Ulrich Petersen (1965-1969) as zoned cordilleran de-

posits. Benjamin Austria in 1976 estimated the temperature of formation of these deposits as between 200°C and 400°C with many values found near 300°C. This range is consistent with the estimates made for Lepanto by Gonzalez in 1957.

Gold and silver deposits form veins in the vicinity of Baguio City. In Acupan, these veins are found in a young volcanic plug which may have formed in the Pliocene or even the Pleistocene. Charred wood within the plug indicates that there were already forests covering the volcano during the time it was active. The Acupan mine remains very hot. Water close to boiling point is being discharged through drill holes at deep levels. Quartz and calcite, a calcium carbonate, from the veins also contain fluid inclusions. Temperature determinations using these inclusions give a temperature of around 250°C.

Gold deposits associated with Pliocene volcanic activity are also found in Masbate. In Surigao, the gold-quartz veins are related to Miocene diorites and andesites.

In addition to metallic ore deposits, non-metallic mineral resources are also extracted from Neogene rocks. The most important in terms of volume and value are the cement raw materials, especially limestone. Most of the cement plants utilize Miocene limestone which is well-developed in many parts of the Philippines. The majority of Philippine limestones are made of calcite with small amounts of silica and magnesia added. Limestones with significant amounts of magnesium are reported in Northwestern Pangasinan and in Zamboanga del Sur. The most abundant occurrence of carbonate sedimentary rocks, rich in magnesium, is in the Carcar formation of Cebu. These are so rich in magnesium (MgO ranging from 15 to 20.69 wt.%) that these can be classified as calcareous dolomites. Ruperto Jagolino (1960) suggests that the dolomites of Cebu were originally limestones. Replacement of the calcitic limestones resulted in alteration and leaching much later than its deposition. Seawater contributed to the replacement of the limestones.

Cement raw materials are abundant in the Philippines. There are more than enough for utilization by future generations. There are no anticipated shortages with regard to this construction material.

Silica sand, used in making glass, bottles and other products, is also found in Neogene rocks. Flintgrade silica sand deposits are found in the southwestern coast of Palawan. The Lower Miocene Tagbita sandstone contains 40% to 50% quartz, 15% to 20% feldspar, 30% to 40% clay, and 1% to 2% iron oxide. In addition to the sandstone, silica beach deposits are found along the coast, which the weathering of the sandstone deposit has produced.

It is therefore evident that numerous benefits have been derived from the complex events that occurred during the Neogene. Further exploration and utilization of these resources require a grasp of the geologic history of the country during the Neogene. A better understanding of the past will also be gained as detailed studies are made on the environment which made possible the formation of energy and mineral resources.

Chapter Five

The Quaternary:
THE PHILIPPINES IN THE AGE OF FIRE AND ICE

"There is a period called 'the supreme years' by Aristotle, at the end of which the sun, moon, and all the planets return to their original position. This 'supreme years' has a great winter, called by the Greeks *kataklysmos*, which means deluge, and a great summer, called by the Greeks *ekpyrosis*, or combustion of the world. The world, actually, seems to be inundated and burned alternately in each of these epochs."
Censorinus—*Liber de die natali xviii*

Developments which began 40 to 60 million years ago led to a slow cooling of the earth. While a warm climate still favored the growth of mammalian forms in the middle of the Cenozoic epoch, tectonic upheavals accelerated the cooling process. By Pleistocene time, beginning some two million years ago, glaciers

had formed in many parts of the earth. These lowered the sea level and exposed areas which until then, and again subsequently, were submerged beneath the surface of the oceans. Man, making his first appearance in this period, was driven to the tropics. Man's presence in the Philippines has been traced to this epoch. In this same epoch, major changes in the structure of the earth occurred, including reversals in the polarity of the magnetic field. This phenomenon in turn has led to climatic changes and to mutations in life forms. These transformations have been traced in the Philippines by means of fossils and formations. The contours of the Philippine land and sea profile during the periods of lower sea level may be reconstructed, to show connections and relationships with other Asian countries. "Land bridges" during this epoch served both as links and as habitats themselves, as shown by fossils. Altogether, the Pleistocene epoch was marked by vital, and even extraordinary, developments which have vastly influenced terrestial and, in particular, Philippine life, including agitations from space in the form of tektites, and fiery convulsions from the depths of the earth itself.

A CREEPING chill spread over the globe as the cooling of the earth's climate that began during the Eocene, 40 to 60 million years ago, persisted through the Neogene and culminated in the widespread advance of ice sheets or glaciers during the Pleistocene, an epoch which began more than one and a half million years ago. These continental ice sheets, similar to the glaciers that now blanket Greenland and Antarctica, covered vast areas of Asia, North America and Europe. Their distribution is illustrated in a map among the plates. In the southern hemisphere glaciers covered the southern Andes, the highlands of Tasmania and New Zealand, and the area around Mount Kilimanjaro and Mount Ruvengori in Africa. The advancing glaciers scraped and bruised outcrops of rocks, sculpted valleys, transported huge blocks of rocks and deposited glacial features such as moraines, eskers and glacial soil known as till. (Pleistocene glaciation exerted an influence on American history. The glaciers removed fertile soil from the North and deposited this in the South. In addition to other factors, this necessited the development of the north as an industrial region and promoted agriculture in the South.) The growth of glaciers drew water from the sea, lowering the sea level by as much as 240 meters below the present level and exposing areas now submerged. These areas served as pathways for

the migration of plants, animals and man between Continental Asia and the present archipelagoes of Southeast Asia.

Owing to a combination of factors, glaciers advanced and retreated during the Pleistocene. Man evolved during this epoch of fluctuating climate. The spread of ice in the northern latitudes pushed man and other forms of life to the tropics. The first signs of man's presence in the Philippines have been traced to this epoch. Details concerning these first Filipinos will be discussed in the second part of this volume.

The advance and retreat of glaciers have not been fully explained. Among the factors that have been proposed as possible causes of the phenomenon are variations in the heat output of the the sun; the passage of the solar system through regions of interstellar dust in our galaxy, the Milky Way; shielding of the earth by periods of volcanic activity; shifting of the crust of the earth relative to the axis of rotation of the planet; and wobbling of the earth's axis of rotation. The diverse factors are charted in a diagram among the plates.

Glaciers grow because of an increase in the snowfall during winter and a decrease in the amount of melting in the front of glaciers due to cool summers. In the northern latitudes, there are regions of permanent snow and ice, so that warm winters would not cause melting of snow but would favor increased snowfall. The temperatures of summer and winter are affected by the degree of tilt of the earth's axis of rotation because the amount of heat from the sun falling on the earth's surface depends upon the degree of inclination with respect to the sun. At the poles, the surface is steeply inclined with respect to the rays of the sun; at the equator, the surface is nearly perpendicular to the rays. The position of the axis of rotation will therefore affect the warmth of summer and the coldness of winter. This position varies with the gravitational influences of the sun, moon and large planets like Jupiter. The cycles of wobbling or precession of the earth's axis were calculated and correlated with the advance and retreat of glaciers by the astronomer and mathematician M. Milankovitch. Estimates of the changes in the temperatures of the oceans show that there is a close correspondence between the cycles determined by Milankovitch and the temperature variations in the oceans, and presumably also the amount of glaciation. However, glaciation was extensive only during the

Pleistocene and the Permian within the Phanerozoic eon. Other factors besides the wobbling of the earth's axis must have combined with the cyclical variations in the relative temperatures of summer and winter to give rise to glaciation.

In the northern hemisphere, glaciation began toward the end of the Neogene, during the Middle Pliocene, 3.2 million years ago. Studies by Robert Thunell and Lloyd Keigwin on the oxygen isotopes in the foraminifera *Globigerinoides ruber* taken from sediments in the Mediterranean, reported in 1978, indicate that during this time the surface temperature of seawater decreased by 2° Centigrade and that the sea level dropped approximately 100 meters. Their observations are consistent with the previous work of N. J. Shackleton and N. D. Opdyke in 1977.

The Pleistocene, however, is not defined on the basis of the onset of glaciation. The accepted base of the Pleistocene is recorded in the sequence of rocks in Italy known as the Calabrian. The boundary, according to W. A. Berggren and B. Haq in 1976, is somewhat closer to our time than magnetic reversal of poles, the so-called Olduvai Event, which took place about 1.8 million years ago. It is essentially synchronous with the last appearance of the foraminifera known as *Globigerinoides obliquus* extremus and slightly younger than the first appearance of the foraminifera *Globorotalia truncatulinoides*, *Gephyrocapsa oceanica*, and *G. caribbeanica*. Many paleontologists (e.g. Blow, Berggren and Postuma), use the appearance of *Globorotalia truncatulinoides*, associated with the Olduvai event, as the base of the Pleistocene. This foraminiferal zone is recognized in the Philippines by Wataru Hashimoto and Guillermo Balce in their 1977 paper, "A New Correlation Scheme for the Philippine Cenozoic Formations." The Quaternary may therefore be regarded as beginning at about 1.6 to 1.8 million years ago.

As many as six major advances of glaciers are recognized in the northern hemisphere. These events are separated by warmer interglacial episodes during which the ice cover melted. With the melting of the ice, the sea level rose. The sequence of glacial, interglacial and high sea level stages that are often regarded as the subdivisions of the Pleistocene is shown in the following Table.

QUATERNARY OVERVIEW

	MAGNETIC Polarity / EPOCH EVENT		V28-238 stages	ka BP	Northern Europe	British Isles
HOLOCENE			1	13		Flandrian
UPPER PLEISTOCENE	BRUNHES		2		Weichsel *	Devensian
			3			
			4			
			5a			
			5b		Brorup	Chelford
			5c		Amersfoort	Wretton
		Blake	5d	118		
			5e	128	Eemian +	Ipswichian Trafalgar Sq
MIDDLE PLEISTOCENE			6		Warthe *	
			7a		Eemian +	Ipswichian Brundom ?
			7b			
			7c	250		
			8		Saale *	Wolstonian
			9		Eemian +	Ipswichian Ilford
			10	350	Saale *	Anglian
			11		Holstein +	Hoxnian
			12	440	Elster *	Anglian
			13		Holstein +	Hoxnian
			14	500		
			15			Cromerian
			16	590	Elster *	Bestonian
			17		Cromerian +	Pastonian
			18	640		
			19		Cromerian +	
EARLY PLEISTOCENE	MATUYAMA		20	700		
			21		Cromerian +	
			22	780		
			23		Menapian	Baventian ?
		Jaramillo	24	900		Antian
					Waalian	Thurnian
					Eburonian	Ludhamian
						Baventian ?
				1.61 M		
	Olduvai					

Ka = Thousand Years

* Glacial
\+ Interglacial

CHRONOLOGY, PERIODICITY, AND CHARACTERISTICS OF AVERAGE BRUNHES PALEOCLIMATIC CURVE IN WESTERN EQUATORIAL PACIFIC (from Mark Valencia)

Unit	Duration ($\times 10^3$ yr)	Midpoint ($\times 10^3$ yr B.P.)	Half cycle ($\times 10^3$ yr)	Whole cycle ($\times 10^3$ yr)	Remarks
B1	0–11.5§				
B2	11.5–84	48			Warmest cold
			56		
B3	84–124	104		96	
			40		
B4	124–163	144			
			37		
B5	163–199	181		72	
			35		
B6	199–234	216			Longest cold
			32		
B7	234–261	248		78	
			46		
B8	261–327	294			
			49		
B9	327–348	343		83	
			34		
B10	348–396	377			
			39		
B11	396–436	416		80	Warmest warm
			41		
B12	436–478	457			
			47		
B13	478–529	504		87	Least fluctuation
			40		
B14	529–559	544			
			54		
B15	559–627	598		97	
			43		
B16	627–656	641			Shortest cold
			31		
B17	656–688	672		79	Greatest fluctuation
B18	688–751	720			
			42	84	Coldest cold

The table also includes the nomenclature used for reversals of the earth's magnetic poles. The magnetic fields of the past are recorded in some volcanic and sedimentary rocks. In volcanic rocks, high temperatures prevent minerals from becoming magnetic. However, as the rock cools the minerals become magnetized and in this way it becomes possible to record the direction of the earth's magnetic field. In sediments, magnetic minerals slowly being deposited behave like tiny compasses and orient themselves in the direction of the earth's magnetic field during their time of deposition. During the Pleistocene, five reversals of the polarity of the magnetic field are recognized; these have been dated by radioactive methods. As markers on the time horizon, these reversals are useful not only in the study of glaciation and climatic changes but also in dating evolutionary changes in man and other living things.

During a polar reversal, there is a spell during which the earth's magnetic field disappears. Because of this, radiation shield offered by the magnetic field also vanishes and radiation from the sun, unimpeded and therefore more intense, reaches the earth's surface. During these periods, mutations in the gene carriers of heredity become more abundant, resulting in changes in forms of life on earth.

Temperature changes during the Pleistocene are recognized today in the shells of marine organisms and in the abundance of certain kinds of organisms, especially foraminifera which have a well-identified preferences for one or another kind of temperature. In the Pacific, the surface temperatures of the ocean may have differed by three or four degrees centigrade during the glacial and interglacial stages. One of the plates shows graphically the temperature variation for the western equatorial Pacific. Mark Valencia in 1977 correlates this variation with other areas in the equatorial Pacific and with areas in the east, southeast and the northeast parts of the Pacific Ocean. It has been established, however, that the pattern does not extend to the Southern Ocean, and Valencia interprets this as being consistent with a modified "Milankovitch" hypothesis.

The past climate of the Pacific, as summarized by Valencia, is shown in a chart among the plates. The Philippines must have been affected also by climatic changes during the Pleistocene. A climate cooler than our present one accompanied the glacial

stages, perhaps even enough so that snow might have appeared in the mountain ranges as temperatures dropped. In nearby Taiwan, evidence of glaciation is observed in mountains from 3270.9 meters to 3884 meters in high according to C. Lin in 1963. Southwest of the Philippines, in Sabah, there is abundant evidence of glaciation around Mount Kinabalu which rises to 4100 meters above sea level.

Marks of glaciation include rock surfaces polished by erosion by ice, steep-walled mountain valleys known as cirques, and moraines, which are glacial deposits of earth and rocks. Features of glacial erosion and terminal moraines occur down to about 3050 meters above sea level. Wood from a glacial deposit was dated by H. Newton-Smith and G. Wilford in 1968 at 34,300 years old. The minimum age for the deglaciation or melting of the ice at the summit of Mount Kinabalu was placed at 9,186 years ago (plus or minus 120 years) by John Flenley and Robert Morley in 1978. Prehistoric Filipinos who passed by Sabah must have seen the ice-capped peaks of this mountain. Although there is no evidence yet of a similar condition in the Philippines, studies on the morphology or shape of the mountain peaks of this country and Quaternary deposits may eventually disclose the effect of glaciation on the past climates of the Philippines.

The rise and fall of the sea level significantly altered the shape of land in the Philippines. The effect of a 240 meter fall in sea level suggested by B. C. Batchelor, as cited by D. H. Stauffer in 1978, may be approximated by tracing a horizontal line along the present 200-meter depth and this shows that the Philippines would be connected to Borneo, and that various islands within the archipelago are linked together at that depth were the sea so much lower. The land exposed would permit communication by land between the Philippines, the rest of Asia and perhaps even Australia. That such interchange indeed took place is supported by the occurrence of large land animals and remains of man in the Pleistocene rocks of the Philippines, and also by the distribution of land plants and freshwater fishes in Borneo, Australia, Taiwan and in the Philippines. We shall return to this in the discussion of Pleistocene life.

These exposed land areas have been called "land bridges." Some have doubted the existence of these features (e.g. Eric Ca-

siño, 1978), saying that bridges are useful only for passage and not for living, and that there is geophysical evidence against the existence of these bridges.

These are hardly tenable notions. With respect to the first claim, if any land were accessible to migrating life at any given time, without foreknowledge that the same land would be awash in a few centuries, there is no reason to think that the living being to which it becomes accessible for any duration would not be prompted to turn into its habitat. The discovery of coal layers in the Sulu Sea provides evidence that terrestrial life occupied areas now submerged. We may also take note of present-day "land bridges" such as the Isthmus of Panama, the Isthmus of Thailand, and the Tayabas Isthmus in Quezon province. The existence of abundant life established upon these areas clearly shows that life may flourish on relatively narrow strips of land. The persistence of the present-day habitable land bridges in Thailand and Central America refutes whatever indirect geophysical evidence may be offered against land bridges as earth features. Furthermore, seismic surveys show that ridges exist along Palawan and in the Sulu Sea. Their absence today between Taiwan and Northern Luzon does not necessarily mean that in the geologic past, there were never land connections between these islands. Trends of mountain ranges, volcanic belts, fault zones and other island arc features may be traced northward to Taiwan. Recent geologic movements could easily disrupt former land connections that earlier processes of mountain building had built.

The existence of "land bridges" is therefore acceptable as a hypothesis to explain the distribution of terrestrial life in the Philippines and Southeast Asia.

Large areas of land would be covered by the sea if the sea level were higher or if the land were lower. The contour of the Philippines along the 100 meter elevation is illustrated in a map among the plates. Central Luzon would be a seaway, and ocean waves would pound on both sides of the Zambales Range and of the Sierra Madre Range. Mindanao would break up into any number of islands. The illustration would represent the shape of the Philippines before Quaternary uplift, or during occasions of high sea level.

There is a good amount of evidence that the sea reached higher grounds during the Pleistocene. Marine terraces cut by wave action of the sea are uplifted in various places, including the Ilocos provinces and Pangasinan in Northwestern Luzon; Lubang Island; Southern Batangas; Quezon and Camarines Norte in Southern Luzon; Samar, Leyte, and Cebu in the Visayas; Cagayan de Oro and Zamboanga in Mindanao; Mindoro and Palawan in western Central Philippines. In the island of Cebu, as many as seven terraces are recognized by George D. Louderback in 1934, with the highest terraces reaching 900 meters. As early as 1924, Roy E. Dickerson noted:

> "The beautiful Pleistocene limestones exposed in the end of the northwestern peninsula of Leyte offer an exceptional opportunity for the study of the conditions of formation of coralline limestone and allied problems. A cursory examination of these beds seems to indicate that most of the coral species still flourish in the neighboring waters. There are several marine terraces which denote successive uplifts, and each is covered by a thick deposit of coralline limestone. The underlying shales and sandstones of the Vigo group are exposed in a few places in the vicinity, and the unconformity between these beds and the overlying Pleistocene limestone is well marked. The same relation exists between the horizontal Pleistocene deposits and the well-folded Malumbang coralline limestones and interbedded marls at a point about half a mile south of Balite, a small barrio (village) on the west coast of Leyte."

Further on, Dickerson states:

> "Nearly all the large islands show distinct terracing in places, but attempts to correlate these terraces from island to island will lead to failure, since there are many evidences of Pleistocene and recent differential movements. These Pleistocene terraces, as a rule, are mantled by a coralline limestone with which is associated a characteristic molluscan fauna. . ."

Regional differential movements are exemplified in western Central Luzon, where terraces 20 meters above sea level are present in Lingayen Gulf, while Kaybobo Point, an uplifted terrace, is 1.5 meters above sea level. The latter was dated by radiocarbon methods to be 2365 years old.

Uplifted marine terraces have also been observed in Sabah and in Taiwan, and there, too, differential movements have been deduced. Detailed studies of earth uplift in Taiwan were made by Tsung-Hung Peng, Yuan-Hui Li and Francis Wu in 1977. In terraces dating back to 7530 years ago, elevations up to 20 meters were measured. These measurements were combined with the data on the rise of the sea level during the last 9000 years to obtain the uplift rates. The curve for the rise in sea level is shown in a diagram among the plates. Uplift rates of about 5.0-0.7 mm/year were established for the Eastern Coastal Range, the Hengchun Peninsula in the South and the area in the west central part of Taiwan. The rate of uplift in the northern coastal area was small, about 2 mm/year from about 1500 years before the present to 5500 years ago; but it was 5.3 mm/year from 5500 to 8500 years ago. A pattern similar to that observed in Northern Taiwan is noted for samples from the Ryukyu Islands.

Applying a similar approach to the uplifted terrace in the Kaybobo Point, an uplift rate varying from 0.6 to 1.0 mm/year is obvious, depending on whether Nils-Axel Morner's or F.P. Shepard's curve for the rise in sea level is adapted. Although lower than the values determined in Taiwan, this rate is rapid compared with many geological rates. Inasmuch as faster rates may be possible as indicated by the studies in Taiwan and in the study of the Intramuros area by F. Voss, it is important to obtain more measurements on the rate of uplift in the Philippines because these will affect the planning for human settlements in coastal communities.

There is, however, an alternative explanation for marine terraces as suggested by K. K. Verma and V. B. Mathur in 1978, who studied marine terraces in the west coast of India. They correlated these terraces with similar ones in stable areas in other parts of the world. In view of the worldwide similarity in terrace elevations, Verma and Mathur interpreted terraces to be indicative of a systematic lowering of the sea level since the Pleistocene. The highest terrace at 180 to 220 meters above the present sea level is interpreted to be the pre-Glacial sea level. The works of S. W. Woolridge and H. C. K. Henderson (1955), J. K. Charlesworth (1966) and Arthur Holmes (1972) are cited by Verma and Mathur as providing evidence that during the earliest Pleistocene the sea level stood 200 meters higher than

it does today and that since then it has been falling. A summary of their observations in Saurastra, Northwestern India is listed in the following Table:

Quaternary High Sea Levels of Saurastra, India

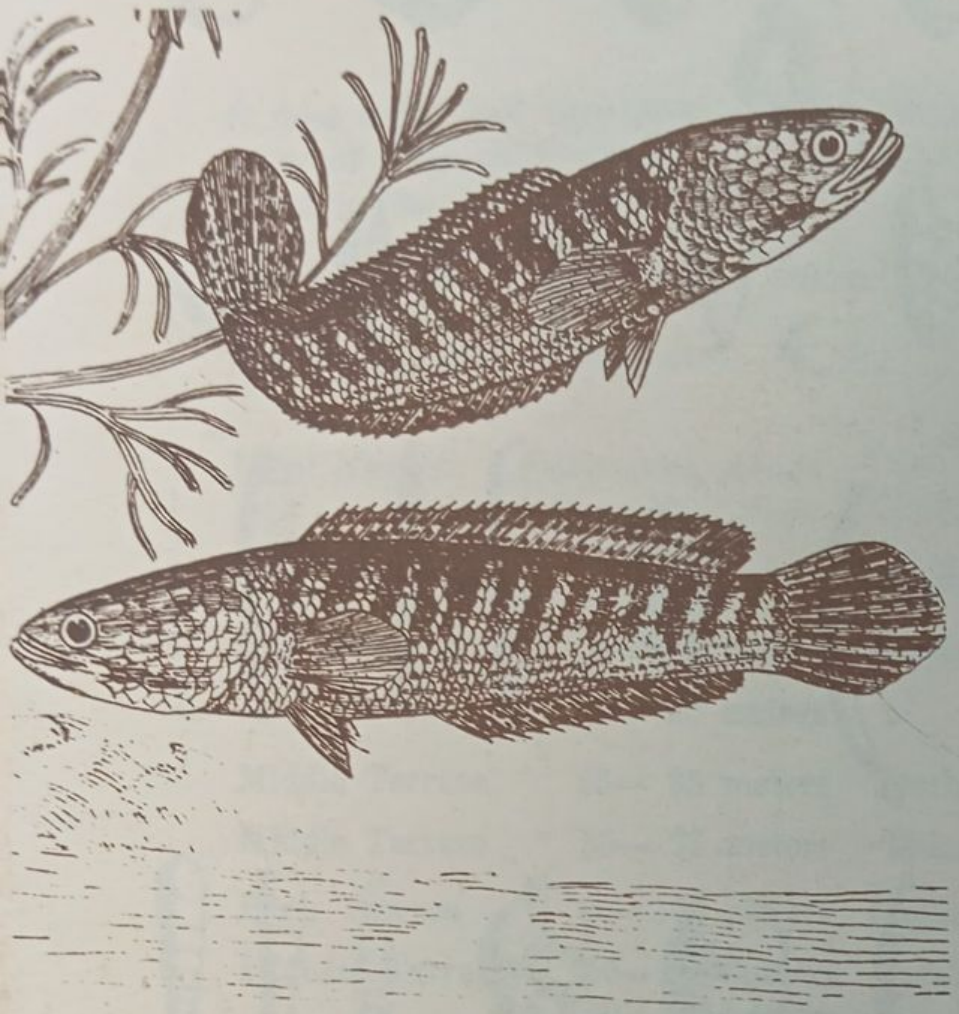
Marine Terraces of Saurastra

Local Names	*Elevation Above Mean Sea Level*	*Standard High Sea Level Sequence*
Lowest Terrace	2— 3 meters	Flandrian
Low Terraces	4— 6 meters	Monasterian
	10— 20 meters	
Middle Terrace	25— 35 meters	Tyrrhenian
Middle Terrace	55— 75 meters	Milazzian
High Terrace	80—100 meters	Sicilian
Highest Terraces	150—160 meters	Calabrian
	180—220 meters	

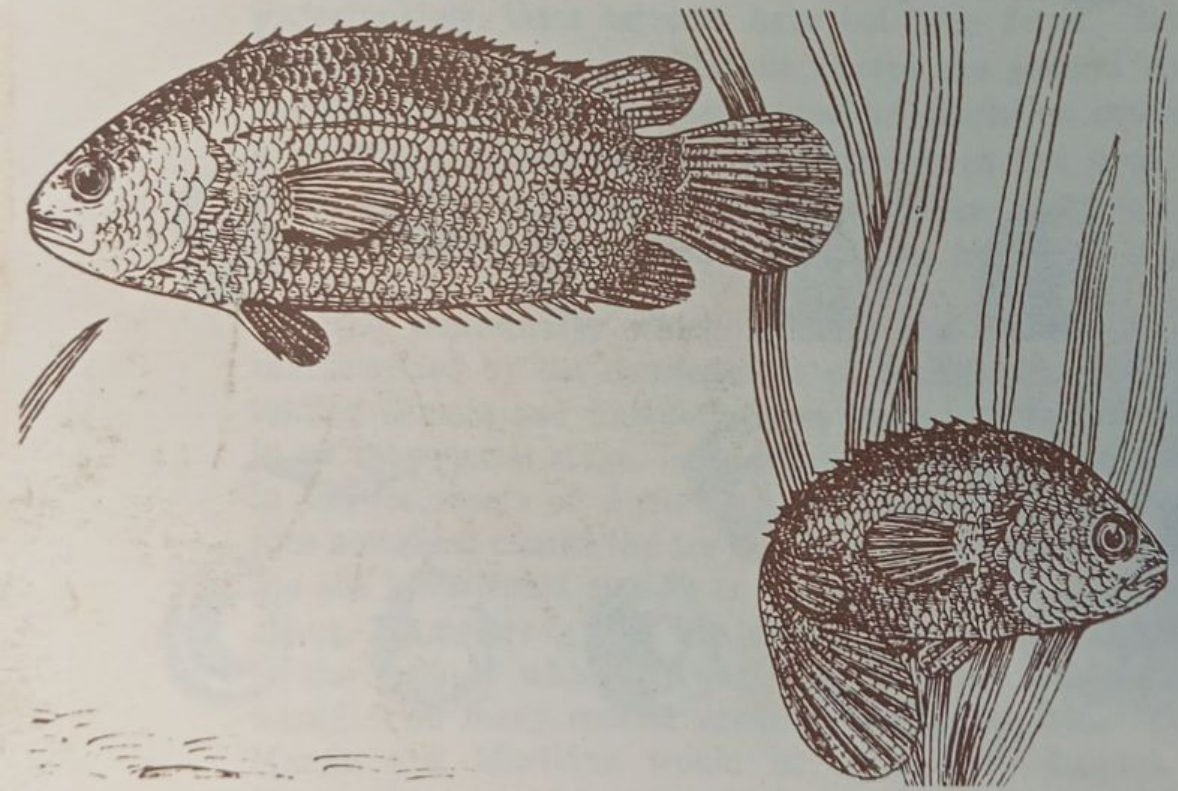
Unfortunately, these terraces have not been dated. Despite this shortcoming, Verma and Mathur regard the general lowering of the sea level as having been caused by glaciation combined with a growth of ocean basins. An increase in the area of ocean basins without significant changes in average depth would indeed result in a progressive decline of the sea level over a period.

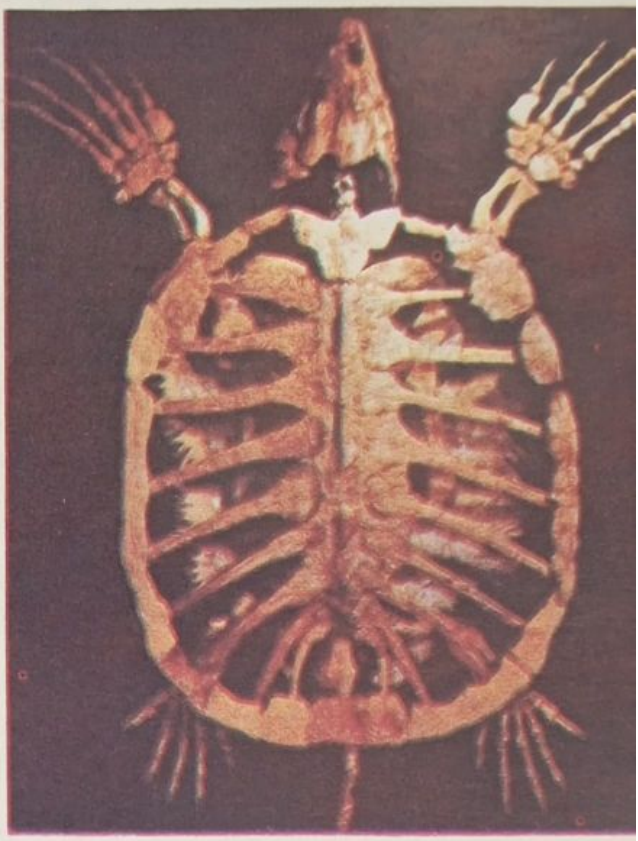
The Quaternary, which includes the present, is therefore characterized by the development of continental glaciation, fluctuating climate and fluctuating sea levels. Although we are now in an interglacial stage, large amounts of water are still trapped in the ice sheets of Antarctica and Greenland. If man's activities somehow caused the ice sheets in these areas to melt rapidly, the sea level would rise 50 to 70 meters and eventually settle to about 35 meters above the present, after crustal adjustments to the load of added seawater has reached equilibrium. This would flood many coastal areas in the Philippines. The City of Manila and Marikina would be submerged. Laguna Bay and Manila Bay would be connected.

Tertiary **Foraminifera** *from Luzon Described by Felix Karrer (1878). These are skeletal remains of marine microorganisms.* **Globigerina** *(no. 23) forms a calcareous ooze in deep sea basins.* **Quinqueloculina** *(no. 7) is a miliolid; nos. 24, 25, 26 and 27 are rotalids.*

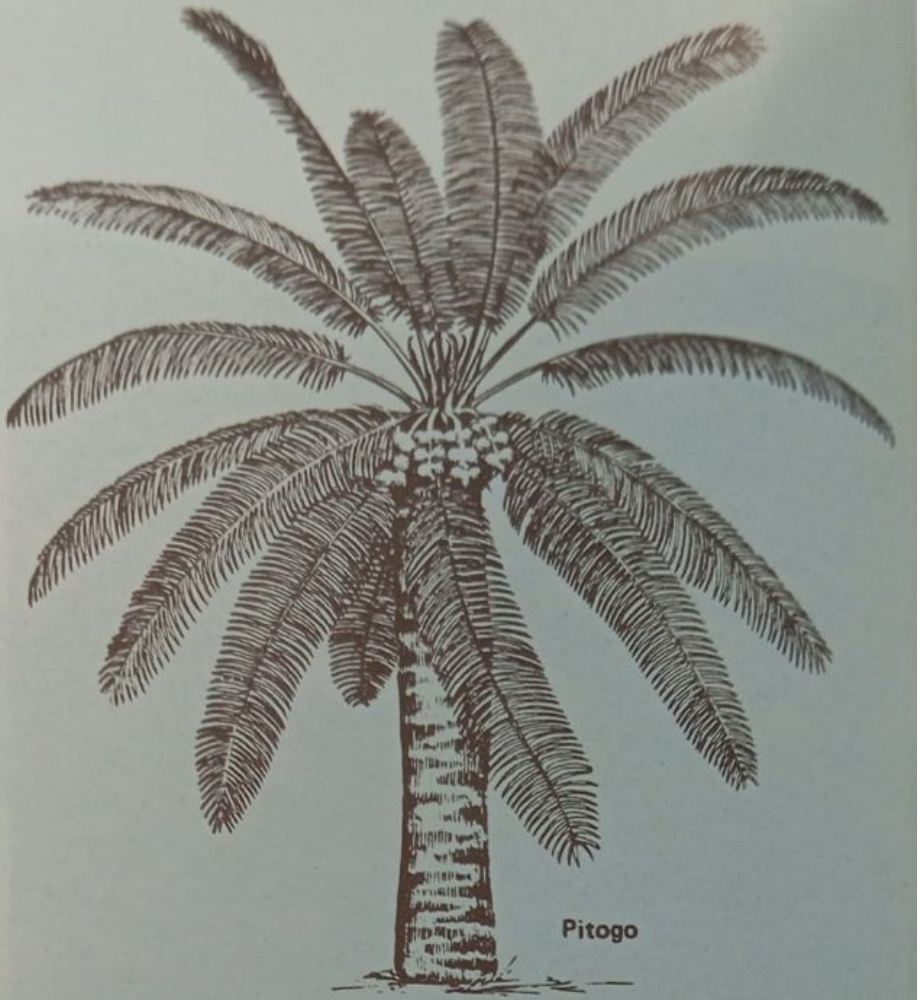


A fish imprint (below). The **dalag** *or mudfish (left) and the climbing perch (below) can survive periods of drought. Land animals evolved from fishes that developed the ability to survive periods of aridity in the Devonian Period.*





Crinoids (above), related to sea urchins and starfishes, flourished during the Permian. Turtle skeletal remains (above, right) are recovered in Pleistocene rocks of the Philippines. The turtle (right) is a member of the reptilian class that included the dinosaurs which were dominant in the Mesozoic Era.



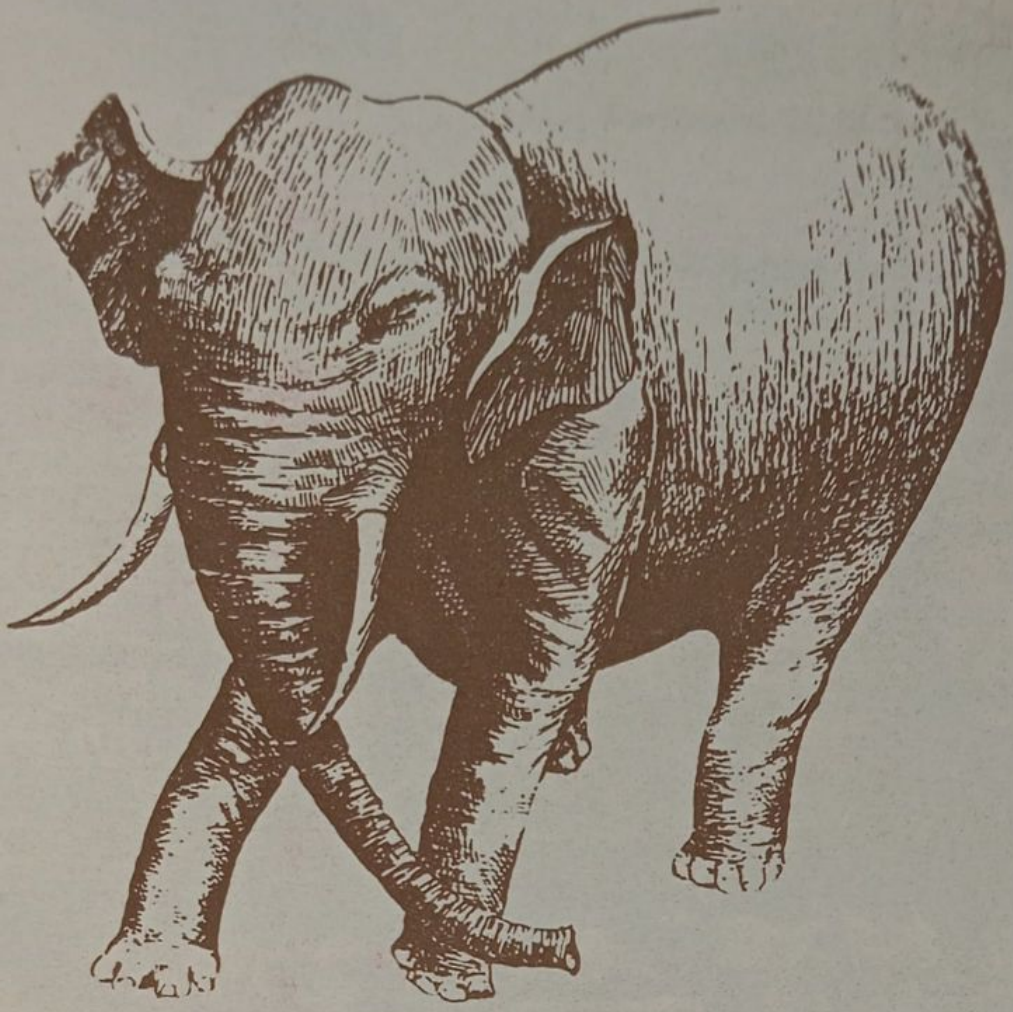
Pitogo

Above: A fern imprint.

The cycad (right) has persisted since the Mesozoic Era. Pollen grains of near shore plants such as the **palomaria** *(right),* **pagatpat** *and* **bakawan** *(facing page, top and bottom, respectively) are recovered from Tertiary rocks in Palawan and Sulu Sea. The mangrove species of SE Asia radiated into the Middle East, Europe and North Africa during the Early Tertiary or Paleogene time.*

SONNERATIA PAGATPAT —Blanco —Miq.

The rhinoceros, (above) dwarf elephant (facing page, top) and other elephants roamed in the Philippines during the Pleistocene.



Elephant remains (tusks, teeth and bones) are shown in the lower part of this and the facing page.

Overleaf: An artist's conception of a Pleistocene landscape in the Philippines.

On the other hand, the growth of continental glaciers drew away awesome amounts of water from the oceans. Ice varying from about 250 to 3,000 meters thick covered North America; in Scandinavia, the thickness of the ice exceeded 2,400 meters. The drawing of water from the seas lowered the sea level by about 100 to 135 meters during the last glacial advance, 10 to 60 thousand years ago. During the Riss or Illinoian glacial period, the sea level may have receded by 200 meters or more. The recession of the sea by this much resulted in the development of underwater limestone caves in the Caribbean which were discussed by Robert Dill in 1977. In the same area, Dill estimates the lowering 10,200 years ago to have been 50 meters.

The fluctuating climate caused changes in the flora and fauna of the northern latitudes. In Sakhalin, for example, late Pliocene flora changed from one containing thermophilic or warm weather species to flora less diverse, according to A. N. Alexandrova. The extinction of about half of the genera of tree plants is related by Alexandrova to the strong cooling during the Pleistocene. A gradual disappearance of warm-weather plants is also noted in Kamchatka by A. I. Chelebayeva in 1976, but this takes place earlier, during the Late Miocene.

While the glaciated regions became inhabitable, the Philippines continued to provide habitation to plant and animal life. As pointed out in the previous chapter, many Neogene and Pleistocene marine organisms are still found in Philippine waters today. The Philippine environment may therefore be said to have offered a chance for survival to organisms that would have become extinct in the harsher environment of the northern latitudes. If the maximum difference in the temperatures of the Pacific between glacial and interglacial stages were only three to four degrees centigrade, the difference appears to be sufficiently comfortable to permit pre-existing marine organisms in the Philippines to survive to the present. There were, however, changes in the relative abundance of some organisms; cold-resistant species multiplied in greater numbers than those which preferred warmer temperatures. This is the basis of studies of ancient climates of the equatorial Pacific and other parts of the world.

Warm-weather land animals were driven southward with every advance of the ice sheets of China, Siberia, Europe, and North America. Grazing herds of elephants, rhinoceri, varieties

of the pygmy elephant known as *Stegodon*, ancient horses, wild boar, and buffaloes migrated wherever food and a hospitable terrain were available. On the spoor of these migrating herds were the predators, including the saber-toothed tiger, related wild cats and even early man. Land animals and plants could have reached the Philippines by way of two possible routes, a northern route from the Asian mainland through Taiwan, and a southern one through Borneo, Palawan, and Mindoro or Borneo, Sulu, and Mindanao and possibly, also Celebes-Halmahera.

The presence of temperate flora in the Central Cordillera which consists predominantly of pines suggests that there was an ancient land connection between Luzon, Taiwan, and the Asian mainland where similar temperate flora are found. G. H. R. Von Koenigswald (1956) also cites two items of evidence in support of a connection between the Philippines and the Asian mainland in the distant past. He mentions the kinship of the *tamaraw* to the *Bubalus mephistopheles* of China and the existence of the parasitical snail-borne disease called Bilharziosis in Japan, Southern China, the Philippines, and Celebes. The parasite needs as a host in its development certain freshwater shells. Seawater would form a barrier to the snails, hence the distribution of the disease in these countries now separated by sea would support the existence of an ancient land connection. The northern land connections are interpreted by C.C. Lin (1963) as having existed in pre-glacial times and as having persisted up to the Mindel glacial stage, when the connections were broken. His interpretation is shown in a series of diagrams reproduced in the plates. The marked difference in freshwater fishes in Taiwan and Northern Luzon argue against land connections of more recent time than Early Pleistocene.

Similarity of freshwater fishes in Palawan, Eastern Mindanao, and Borneo is offered by Roy E. Dickerson in 1942 as evidence of the existence of the Molengraaff River, a drowned Pleistocene stream which he traces to the South China Sea. The similarity suggests that Borneo, Palawan, and Mindanao formed part of the drainage basin of the ancient river. The shelf areas between Palawan, Mindanao, and Borneo are sufficiently shallow to support the notion that land connections appeared between these islands as the sea level dropped during glacial stages.

Remains of land mammals are found in Luzon, Iloilo, and Mindanao. Their presence lends support to "land bridges" for these land mammals include relatively heavy species such as elephants, rhinoceri, stegodon, and the *tamaraw*, animals too large to be transported by rafts.

The pygmy elephant *Stegodon mindanensis* Naumann whose fossils were collected in 1860 by Karl Semper in Agusan, are probably related to another pygmy elephant found in Fort McKinley (now Fort Bonifacio) named *Stegodon luzonensis* n. sp. by von Koenigswald. These dwarf elephants appear to have ranged from Mindanao to Luzon. Fossils of the *tamaraw* found by H. Otley Beyer (1956) in Novaliches, Rizal also offer proof that the species had a wider distribution in the past than today, when its presence is limited to Mindoro. The elephants were small, including the new species *Elephas beyeri;* but recent discoveries in Cagayan Valley have yielded elephant teeth and hip bones of a type medium to large in size. Other animal remains preserved in the Pleistocene Awiden mesa formation of Cagayan Valley include rhinoceros, pig, carabao, deer, and turtle.

The abundant life recorded in the rocks of the preceding epoch persist into the Pleistocene. The seas, which are an abundant source of food today, must also have supplied food to early man in the Philippines. Coral reefs flourished in the warm seas of the Philippines during the Pleistocene. In Mindoro, Wataru Ishijima identified the following algae or seaweeds from raised Pleistocene coral reefs: *Aethesolithon grandis* Johnson *Amphiroa fragillisima* (Linnaeus) Lamourouz; *Amphiroa cylindrica* Ishijima; and *Jania cfr. dercourti* Johnson.

In the Bondoc Peninsula, the Malumbang formation, dated as Pleistocene by Ernesto Espiritu *et. al.* in 1968, has reefal limestone containing algae, echinoid spines, corals, molluscs and bryozoa, along with foraminifera. The latter include *Alveolinella quoyi, Calcarina hispida* and *Marginopora vertebralis.* The echinoderms, the group which includes starfishes and sea urchins, as identified by Merle C. Israelsky in 1933 are: *Clypeaster* cf. *scutiformis* Gmelin; *C. malumbangensis* Israelsky, n. sp.; *Laganum* cf. *decagonale* Lesson; *Peronella meriilli* Israelsky, n. sp.; *P. ragayana* Israelsky, n. sp.; *Schizaster pratti* Israelsky, n. sp.; and *Pericosmus schencki* Israelsky, n. sp. Earlier, Roy E. Dickerson in

1922 and Warren D. Smith in 1913 had identified the echinoderm *Schizaster subrhomboidalis* Herklots from Bondoc Peninsula.

In the Tartaro formation of Nueva Ecija, dated as Pliocene to Pleistocene by Benjamin Gonzales *et. al.* in 1971, the windowpane oyster, *Placuna placenta,* occurs with ostracods, coral stems and other molluscan shell fragments. Foraminifera from the formation include *Nonion bouseanum, Streblus beccarii,* and *Elphidium advenum.* These fossils indicate a nearshore environment. The Tartaro formation is overlain by the Guadalupe formation which contains plant remains and vertebrate fossils. Some plant leaves are identified as belonging to the *Euphorbiaceae,* the family of the *lumbang* tree.

In addition to these, Wataru Hashimoto in 1969 lists the following corals as present in a recent raised coral reef: *Cyphastrea chalcidicum* (Forskol); *Leptastrea* (?) sp.; *Favia* cf. *speciasa* (Dana); *Favites abdita* (Ellis and Solander); *Goniastraea* cf. *pectinata* (Ehrenberg); G. cf. *retiformis* (Lamarck); *G.* cf. *planulata* M. Edwards and Haime; *Platygyra gracilis* (Dana); *P. phrygiea* (Ellis and Solander); *Symphyllia* cf. recta (Dana); *Acanthastrea* cf. echinata (Dana); *Diploastrea heliopora* (Lamarck); *Pachyseris* sp.; *Fungia* sp.; *Porites* sp.

Also found in Pleistocene rocks are implements of man called *paleoliths.* These include axes, adzes, and scrapers. The association of some of these paleoliths with tektites suggests that man was already in the Philippines as far back as 750,000 years ago.

We shall return to a description of the life and culture of early Philippine man in the second part of this volume.

The tranquil Pleistocene night 750,000 years ago was agitated by a commotion of fiery objects hurled from the sky over vast areas of the Philippines stretching from Pangasinan to the Bicol region. This phenomenon presumably sent the stegodon, elephants, rhinoceri, deer, and buffalo on stampedes across the forests and grasslands of Luzon. Early man witnessing the event would have panicked at the sight of stars falling and the sky crumbling. Similar events took place in Indochina, Indonesia, and Australia. The fiery objects were tektites of unusual shapes and surface textures, dark burnt color or shiny and glassy.

The term tektite comes from the Greek word *tektos,* meaning molten. Although its composition is predominantly 68% or

more silica, it is unlike the volcanic glass obsidian because it does not contain water; and unlike terrestrial rock of equivalent silica content, tektites have more lime and magnesia and less soda and potash. The composition of Philippine tektites is given below. The first column is the first analysis of a Philippine tektite undertaken by T. Dar Juan of the Philippine Bureau of Science in 1928. The second column is the average composition of three Philippine tektites known as rizalites.

Constituent	1	2
SiO_2	71.00	71.17
Al_2O_3	13.98	12.95
Fe_2O_3	0.75	0.65
FeO	4.64	4.76
MgO	2.77	2.73
CaO	3.10	3.50
Na_2O	1.08	1.30
K_2O	2.02	2.23
TiO_2	0.75	0.86
MnO	0.06	0.05
H_2O	——	0.12

The glassy state of tektites suggests that they formed at high temperatures and cooled rapidly. The shapes suggest that tektites were formed as they traveled through air at high speed.

Various suggestions have been made explaining how these unusual objects formed. Four stand out — terrestrial volcanism; lunar volcanism; terrestrial meteorite impact; and lunar meteorite impact. Formation by terrestrial volcanism had long been discarded because of the chemical composition of tektites, which differs greatly from volcanic rocks of the earth, and because the velocities of terrestrial eruptions are not high enough to scatter tektites over the wide areas in which the tektites are found. John O'Keefe in 1978 favors the theory of lunar volcanism in view of findings from Apollo lunar landings, recent studies of tektites found in Irgiz, Kazakhstan, arguments based on chem-

istry, and evidence from aerodynamic experiments. D. H. Stauffer (1978), on the other hand, favors meteorite impact as the origin of the tektites strewn over a vast Australian field, which includes the Philippines. Stauffer attempted to pinpoint the impact crater that produced such a large field and he speculates that it is the size of the Mekong delta in Indochina. The suggestion is difficult to accept.

If these tektites came from the moon, samples already established to have come from that source may be gathered in the Philippines, where these abound, readily available for analysis and eliminating the necessity for a lunar trip. Philippine tektites are likewise useful in archaeology because they would provide a time marker of 750,000 years, which could be correlated across the sea to Indochina, Indonesia, and Australia.

Celestial fire was not the only source of disruption in this warm, tropical haven during the Pleistocene. Earth fire in the form of volcanic eruptions were frequent, undoubtedly sowing fear and inspiring awe all at once, as in fact they still do in our time. This mixed feeling of reverence and fright contributed to the idea that mountains were dwelling places of gods and goddesses. In this way myths and legends developed around volcanic mountains.

Volcanic activity during the Quaternary deposited vast amounts of ash and lava over islands of the archipelago. The foundations of Manila are built on volcanic ash deposited during the Pleistocene. This consolidated ash, known as the Guadalupe tuff, after the quarry in the Guadalupe bridge area where the tuff was originally studied and described, blankets a large portion of the Luzon Central Valley, Rizal, Laguna, and Batangas. Layering and other features in the tuff indicate that some portions were laid down under water. Silicified wood, grass, twigs, and leaf imprints indicate that there were forests and grasslands nearby where stegodon, elephants, deer and other animals browsed. In some places, these land animals are preserved as fossils. The tektite layer in the Guadalupe tuff indicates that the tuff is at least 750,000 years old. Sharks' teeth recovered at deeper portions suggest that the early deposits were laid down in the sea. Manila Bay may have been connected with Laguna Bay. Subsequent faulting and uplift along the Marikina fault formed a barrier between the lake and the Bay. Uplift of the Antipolo

plateau and the relative movement downward of the adjoining block gave rise to the Marikina Valley.

The source of the widespread Guadalupe tuff is not yet established. Similar deposits are found at the rim of Taal Volcano, an active volcano which is a caldera. The caldera rim forming the Tagaytay ridge is believed to be the remains of a larger volcano known as Great Taal. This giant volcano was shattered by a mighty eruption, possibly much like that of the Krakatoa in the last century. The remaining crater formed a lake in the center of which the present day Taal is found.

North of Taal, there is a north-south trending line of non-active and dormant volcanoes in Zambales and Bataan. One of these volcanoes, Mt. Pinatubo, erupted 600 to 8000 years ago. During this period, volcanic debris with a total volume of 7.5 cubic kilometers was deposited on its western side and covered an area of about 250 square kilometers. An equivalent amount was deposited on the eastern side of Bataan during the eruption of Mount Natib about 30 to 100 thousand years ago. The history of eruptions of Mount Mariveles and Mount Natib has been demonstrated, by radiometric dating for the studies on the Nuclear Power Plant site, to have spanned a period over two million years.

A description of the eruptive history taken from the report on studies for the Nuclear Power Plant site follows:

> "...application of statistical methods... indicates that volcanism forming these major edifices proceeded fairly rapidly initially through a span of perhaps 300,000 years, starting about 2.3 million years ago. Relatively few flows or intrusives have been sampled from the period between 2 million and 1.2 million years ago, suggesting a relatively quiescent period. A strong renewed pulse or episode of activity is suggested by numerous flow and intrusive rocks with ages between 1.2 million and 500,000 years... available for sampling on Bataan. A second quiescent period, possibly representing cessation of volcanism in Bataan or stoppage of subduction in the slab below, started about 500,000 years ago."

The history described above shows that volcanic activity persisted through the Pleistocene. A similar history may be expected of

Quaternary volcanoes of similar size in other areas. Mt. Arayat in Pampanga was dated radiometrically in the same study to be 500,000 years old. To the north, along Pangasinan and Tarlac, is a cluster of four volcanic centers dated to be 1.1 to 1.6 million years old.

Further north, in Batanes, the northern tip of the Philippines, there is also a cluster of active volcanoes, namely, Smith Volcano, Babuyan Claro, Didicas Volcano, and Camiguin de Babuyanes. In the Eastern Philippines, a long chain of active and inactive volcanoes extends from Camarines Norte to Cotabato. In Sulu, the Volcano Bud Dajo shows solfataric activity, or hot spring emanations. Kanlaon is an active volcano on Negros Island in the Visayan Sea. North of Mindanao, the active volcano Hibok-Hibok is famous for its glowing avalanche. In Central Mindanao, there is a volcanic cluster consisting of Calayo, Bagang, and Macaturin.

If these volcanoes follow a pattern of growth and eruption similar to those found in Bataan and Zambales, then they were already part of the Philippine landscape when early man reached the archipelago. Because of the widespread distribution of volcanic centers, the inhabitants of the archipelago did not have to travel far to see a volcano. Presumably, earthquakes and occasional tidal waves rocked the islands of the Philippines during the Pleistocene.

The young volcanic rocks formed a cover over Pliocene and older rocks. Most of them are gently dipping or flatlying. Recent movements of faults have offset or moved even these Quaternary formations of rocks. In the Magat Dam site in Isabela, Pleistocene tuffs are displaced along with very young deposits of river gravel by a gently dipping fault known as a thrust fault. A total movement of about five meters is indicated by the fault.

In the Tayabas Isthmus, coconut trees, bridges, sand dunes and many other surface features are displaced to the extent of one to two meters by a single movement of the Philippine fault during an earthquake. The earthquakes we experience are the result of movement along the fractures in rocks known as faults. Stress pent up in the earth is released by sudden movements, producing earthquakes. The Philippines today, as in the past, is a site of numerous earthquakes on account of its geologic set-

ting. Because the Pleistocene Philippines is very similar in geologic environment, it is safe to presume that earthquakes, phenomena common in this Pacific belt of fire, also tore through the lives of early Filipinos. Volcanic earthquakes are also present during volcanic eruptions.

Besides volcanic rocks, other young features of the archipelago formed during the Pleistocene are sand and gravel deposits, soil and alluvium, and coral reefs. One of the unusual reefs formed is the double barrier reef in Bohol. The double barrier reef, illustrated in the plates, is interpreted by M. Pichon (1977) as having been formed by a combination of two processes — favorable tidal currents and initial growth as a fringing reef, followed by subsidence and resumption of growth in the inner barrier.

Although the period of geologic time covered by the Quaternary is short compared with the other epochs and periods of the prehistory of the Philippines, it has nonetheless produced important fuel and mineral resources for the Philippines. The preponderance of volcanism during the Quaternary created a natural setting for geothermal energy. In some places, this volcanism was accompanied by mercury deposits. Chemical breakdown of rocks at the surface formed the life-giving soil that supports us, along with plants and animals. In some places, these soils are useful by themselves as sources of clay for ceramics and pottery; in other places, the soils are enriched with nickel, iron, or aluminum. The transport of rock debris by streams and the winnowing effect of the waves of the sea also produced concentrations of minerals known as placer deposits. The rock debris themselves are useful as construction material in the form of gravel and sand.

Geothermal energy consists of heat flowing from the earth's interior. The amount of this heat is usually negligible in most areas but in island arcs like the Philippines, there are areas where the heat of the earth is abnormally high. These reservoirs of geothermal power are intimately related to the young volcanism of the Quaternary. Most of these areas are found near the Philippine fault. However, there are also andesitic and dacitic volcanoes found along the margin of the intrusives in the Central Cordillera of Luzon which likewise are potentially productive as geothermal areas. Extinct or non-active volcanoes in Bataan, Zambales, Mindoro, Marinduque, Southern Negros, Misa-

mis Occidental, and Cotabato still manifest internal heat and hence could still be tapped for this form of energy. Active volcanoes in Laguna, Batangas, the Bicol Region, and Northern Negros are definitely geothermal areas. Leyte, Surigao del Norte, and Davao del Norte, because of their proximity to the Philippine fault, also have excellent potential as concentrations of geothermal force. Other known geothermal areas are in Palawan, Cebu, Antique, and Capiz.

Hot springs associated with volcanism had been used in the past mainly for health. The early Spaniards, carrying the Latin tradition of hot baths, were particularly attracted to the hot springs beside Mount Makiling and there they built the town of Los Baños and made it famous. Today, these hot spring areas will benefit millions of Filipinos with the power that may be generated from them.

The Tiwi geothermal field in Albay, for example, will provide energy not only for the Bicol Region but also for the Southern Luzon Grid. The development of the geothermal field will benefit the nation as its crude oil requirements are reduced with the development of this indigenous form of energy.

Other geothermal areas are at the exploration and development stage. One recently explored and now being developed is a site in Tongonan, Leyte. Hot springs on the surface and other favorable geological, geochemical, and geophysical features justified initial drilling to a depth of 610 meters. From it flowed hot water with temperatures reaching 190°C, and with a chloride content of 1.5%. On July 24, 1977, a three-megawatt unit was installed and now supplies electricity to Ormoc City. By 1981, 112 megawatts will have been generated, enough to satisfy the industrial needs of Leyte and supply power to a copper smelter scheduled for construction there.

Quaternary volcanism also brought along with it metalliferous deposits in some areas. Near Baguio City, a pipe-like volcanic structure known as the Balatoc plug forms the host for gold deposits in Acupan. This mine also encounters hot water on some levels, indicating that there is an underground hot spring which produces water very close to boiling. Gold occurs in veins passing through the plug and along margins of the plug where fracturing of the rocks produced an aggregate of broken rock

known as breccia. Some zones of the mine contain charred wood, indicating that forests existed above the volcano when the gold deposit was formed.

In Sibuyan Island and in Palawan, mercury deposits are associated with silica bodies presumably deposited by former hot springs. Closely related to these bodies are ultramafic rocks.

Non-metallic deposits are also derived from volcanic activity. Bentonite, a result of the transformation of volcanic glass to clay, has a variety of uses, from drilling to the foundry industry. Volcanic glass in Albay produced deposits of perlite which is used in the manufacture of steel.

Volcanic rocks are also useful as construction material. Adobe, used by Filipinos in the past as well as today, is an attractive rock formed by the consolidation of broken products of explosive volcanism. Multicolored adobe contains darker pebble-sized rocks which are porous. Known as volcanic bombs, they were formed by gases expanding in the molten lava. Thus they are bubbles frozen in the rock. Adobe is quarried from the Guadalupe tuff underlying Metro Manila. Studies in the composition of this tuff also show that it is suitable as an additive in the manufacture of portland cement.

Tektites that fell during the Pleistocene in the tuff of Manila and its vicinity, and in the soils of Pangasinan and Camarines Norte, have yielded scientific information on processes in the evolution of the universe, but they may also be used as gemstones. Local handicraft manufacturers have used these objects in jewelry.

Weathering, the chemical breakdown of rock into soil, is another process that formed important sources of metals. The weathering process is a means of removing some constituents of the rocks, leaving only the metals. In this manner, nickel, for instance, which is present in minute quantities (about 0.2%) in ultramafic rocks, becomes enriched about five times to form what is known as nickeliferous laterite ore. The formation of laterite ore is favored by a tropical climate, abundant rainfall, gentle topography, and adequate drainage to transport the dissolved products of weathering. These conditions are satisfied in areas underlain by ultramafic rocks in Surigao, Palawan, Zambales, and

Davao. Other ultramafic areas in the Philippines are also prospective targets for exploration.

Nickel is a new product of the Philippines. In 1978, it displaced gold from the second place in mineral production in terms of value. A billion tons of ore reserves in Nonoc assures an adequate quantity of nickel for future production. Several billion tons may be expected from the other laterite areas. The process of laterization also raises the amount of iron present in the soil; the larger part of the iron resources of the Philippines is therefore in the soil. When these become extractable, the Philippines will be more than self-sufficient in terms of this extremely important industrial metal, for steel is the backbone of industrialization.

The weathering process also produces soils enriched in aluminum. The aluminum ore known as bauxite is derived from various rocks, preferably those deficient in silica iron. Ultramafic rocks are therefore not suitable as starting material for the formation of bauxite. In the Philippines, bauxite is found in Samar in areas underlain by limestone. A tropical climate and abundant rainfall are favorable for the enrichment of aluminum, as they are for laterite. There are other areas where these conditions and the suitable source material are present in the Philippines. Although there is no present production of this metal important in the making of products used every day by many Filipinos, the aluminum resources of the land will eventually be developed hand in hand with other important resources.

Broken rock and soil are transported by streams, so that they eventually find their way to the sea, the graveyard of all things. In the process of being thus transported, the rock and soil yield heavy and stable minerals which then become concentrated in the form of placer deposits. The concentration could also take place by the winnowing action of sea waves. Among the minerals that form placer deposits are gold, magnetite (iron ore), chromite, rutile and ilmenite (titanium ore), cassiterite (tin ore), platinum, and diamonds. Placer gold and magnetite have been mined in the Philippines. Gold in placers is found in Paracale, Camarines Norte, and in Agusan, Surigao, Mindoro, Isabela, Rizal, and Pangasinan. Magnetite forms sand deposits along the La Union shore, Cagayan, Zamboanga del Norte, and Leyte.

Some deposits of magnetite contain significant amounts of titanium. Recently, some black sands have been found to be rich in chromite.

There are also placer deposits of non-metallic minerals. Important deposits of quartz (silica) used in the manufacture of bottles, glassware, and ceramics are found in Palawan. In streams and on beaches, ordinary sand and gravel are extracted for use in construction. Sand and gravel are also in fan-shaped deposits at the base of mountains where streams drop their load as gentler gradients of the plain are reached.

Inasmuch as the shore line may have been either farther inland or farther offshore during the Pleistocene, depending on the extent of glaciation, placer deposits formed by wave action may be found in areas inland or beneath the sea. Stream placers may also occur along submerged coasts where Pleistocene streams have been drowned by sea, which has risen since the last Ice Age. Tin placers are being mined offshore in Indonesia. Offshore deposits in the Philippines have been barely explored or tapped. It is evident, then, that the sea stores hidden wealth upon which future generations may have to depend for a better life and even for survival. Detailed knowledge of the amount of Quaternary vertical movements of the land and sea would be useful guides in the search for these resources.

The present and the future are part of the relatively short Quaternary Period. The emergence of man, his rise to preeminence, the growth of culture and the development of technology in the effort to reach to the heavens, to uncover rocks to read the unwritten past, to dig deep into the earth to draw resources for the benefit of man, to understand the environment to protect life and improve its quality, are among the manifestations of human intelligence and action that make this brief period unique in the history of the universe. Man reached the Philippines during the Pleistocene in search of shelter or respite from the severe cold in the North. The islands of the Philippines provided more than a warm environment; they also offered a bountiful one, profuse with deer, boar, elephants and other animals. In it plants flourished. Through the centuries, this hospitable island and its plentiful environment — along with its topography of mountains, valleys, and plains, underlain by ancient rocks in

which lies untold mineral wealth hoarded as if by an uncanny spirit — composed itself into the mold that formed the soul of the Filipino people, the innumerable generations of dwellers who achieved a sense of lasting kinship because the land gave them equally, no matter how they looked and whatever distances they had traveled, the safety and permanence, the comfort and certainty of home.

Chapter Six

EVOLUTION OF THE ARCHIPELAGO: A SYNTHESIS

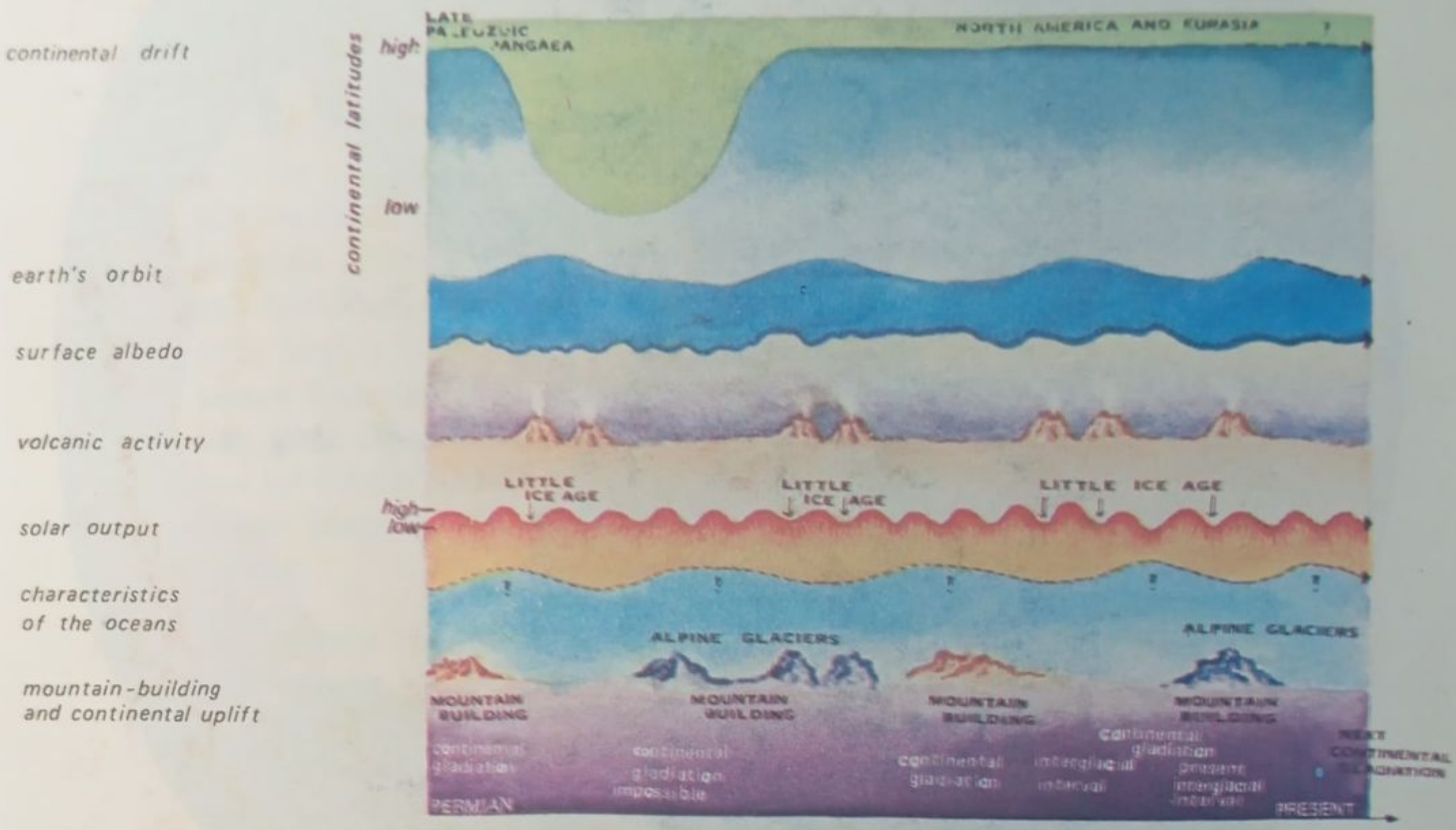
Among a possible few others of the innumerable planets in the numerous galaxies strewn over the universe, earth has been favored with conditions hospitable to life. The Philippines shares with the rest of the earth the features of land and sea that have supported, and enhanced, life. Fortunately, its share of these life-giving elements has been both ample and colorful, providing the country an identity of which Filipinos can be justly proud. Over various eons and epochs covering fifteen billion years, these elements took form, in a process of birth, death, and transformation that may continue interminably. The results of this process in the Philippines, reviewed from epoch to epoch, yield a geologic and geographic profile which summarizes the nature and expanse of the prehistoric setting upon which the history of the Filipino people is laid. No less than history itself, this prehistoric setting has all the tensions and surprises of drama, with land, sea and the principle of life holding the center of the stage.

FOR billions of years the process of creation and evolution built a universe upon which is composed, in ways often surpassing comprehension, the substance of the planets and the galaxies. Fortune or celestial wisdom has ordained that some of these particular spheres in the cosmos shall invite and sustain life. Such a sphere has been the earth, the environment known to man, or the type of man of which we are so far aware. In this environment the dynamism required for life, the rhythm of growth, destruction and change, has been made possible by lands and oceans, and by their separate elements fortuitously arranged to provide life its resources and horizons. From these elements emerged the common origins of life, four billion years ago, and of mankind and its aborigines, forty million years ago, by means of a process still largely mystifying. Particular localities on this life-giving planet treasure their shares of these common elements. Thus, no less than other localities of earth, the home of the Filipino people has its fertile plains, lush forests, long and lofty mountain ranges, scenic beaches, and magnificent reefs to support life and fill the senses.

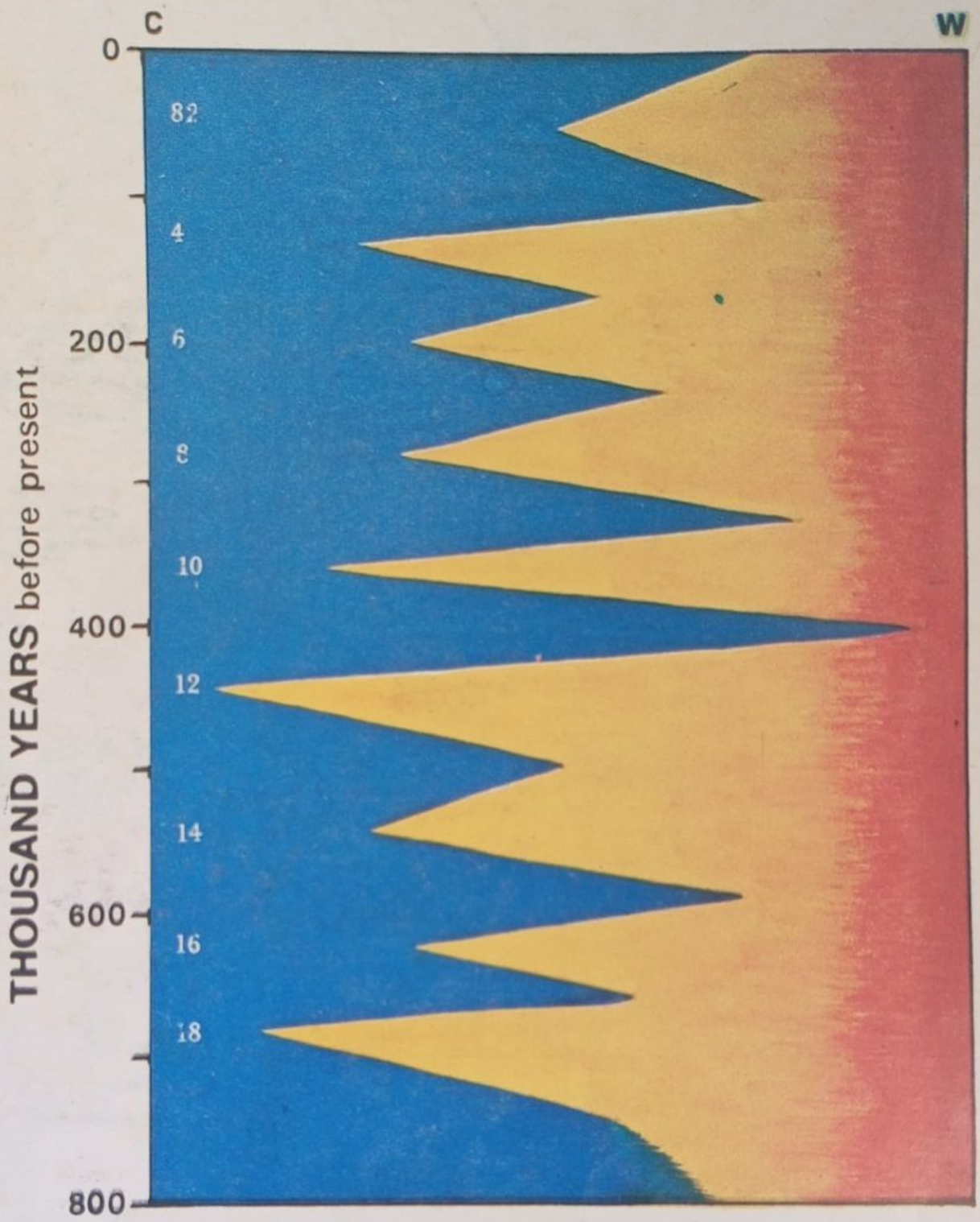
Before rocks in the Philippines received imprints of man's presence in the archipelago, they already bore other records that now enable us to glimpse the prehistoric past, its changing climates, its varieties of life, the turbulence that marked numerous transitions from eon to eon. The earliest record of life in these shores is a Carboniferous coral in Mindoro that lived in tropical seas more than 270 million years ago. Still existing rocks of the Permian period, which succeeded the Carboniferous, contain more varied life forms, including conodonts and foraminifera found in the rocks of Mindoro, Romblon, Panay, and Palawan. Permian sedimentary rocks in Palawan lie on top of older metamorphic rocks. These metamorphic rocks, such as schists and gnessis, have undergone a cycle of deposition, burial and transformation under high temperatures and extreme pressure. Metamorphic rocks characteristic of a continental terrain are found in many areas besides Palawan and Mindoro; these include Ilocos Norte, Quezon, Albay, Romblon, Panay, Cebu, and Zamboanga. In Palawan, these old rocks were formed before the Permian; in Mindoro, they would be Carboniferous, or older.

Pollen grains recovered from oil exploration wells in offshore areas of Palawan and in the Reed Bank show that by the middle

ABOVE:
Distribution of ice caps (white areas) during the Pleistocene.



Variations through time of factors that contribute to the formation of major glaciations. These factors must occur together to produce major glaciations such as those in the Pleistocene.

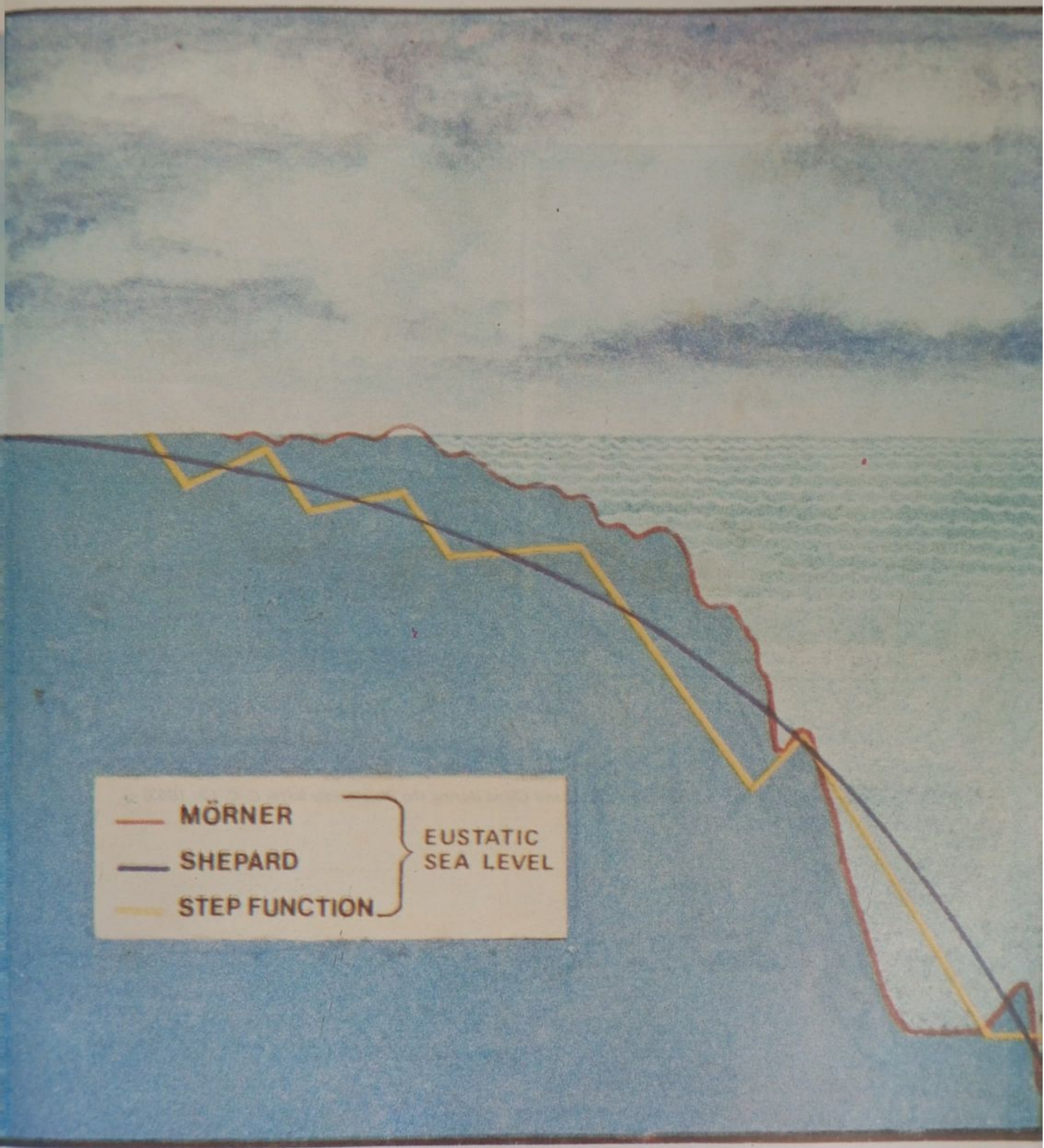


ABOVE:

Fluctuations in temperature for the Western Equatorial Pacific during the Quaternary (after Valencia 1977). The left side represents colder (c) climate while the right side represents warmer (w) times. The shifting temperatures reflect fluctuations in the climate during the Pleistocene.

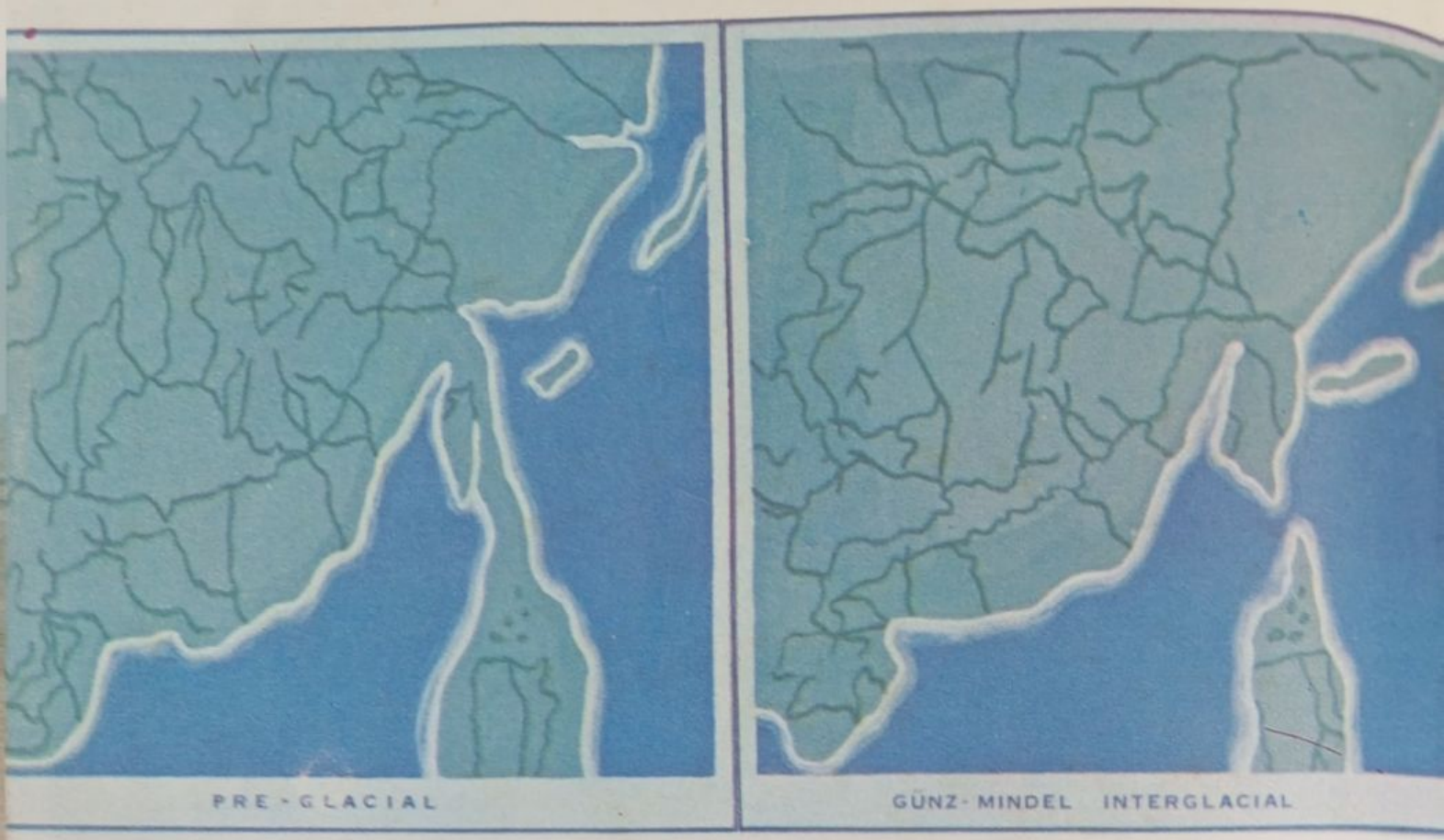
Map of S.E. Asia showing 100 fathom isobath. Areas shaded brown are shallow areas which could be mainly land should the sea recede.

LUZON
SULU SEA
MINDANAO SEA

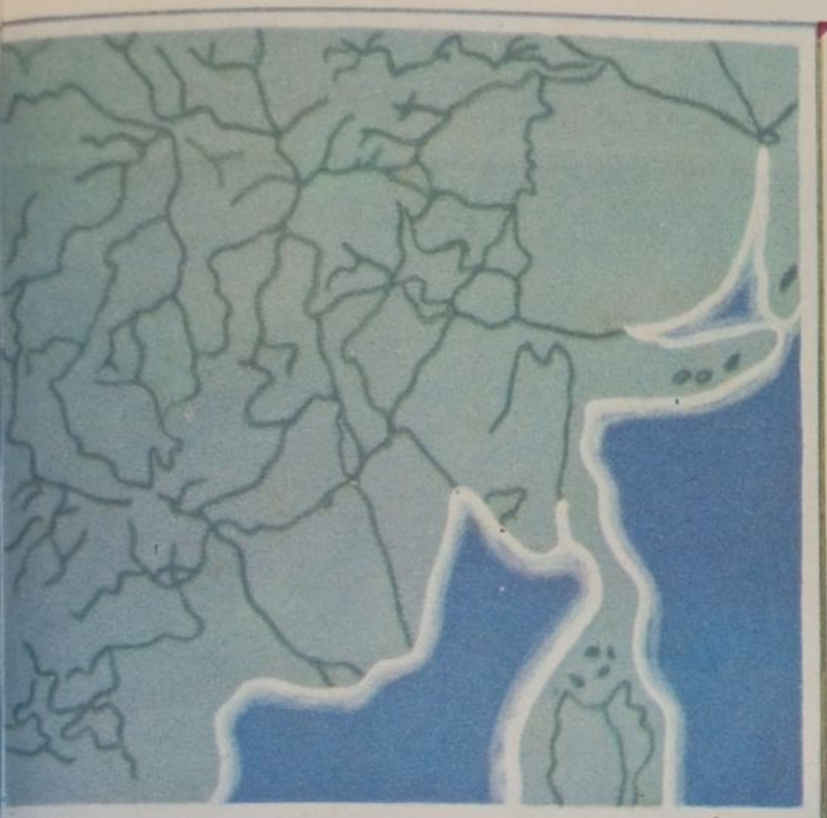


LEFT: Shape of the Philippine Archipelago above 100 meters. Orange areas would remain above the sea if the level were to rise 100 meters.

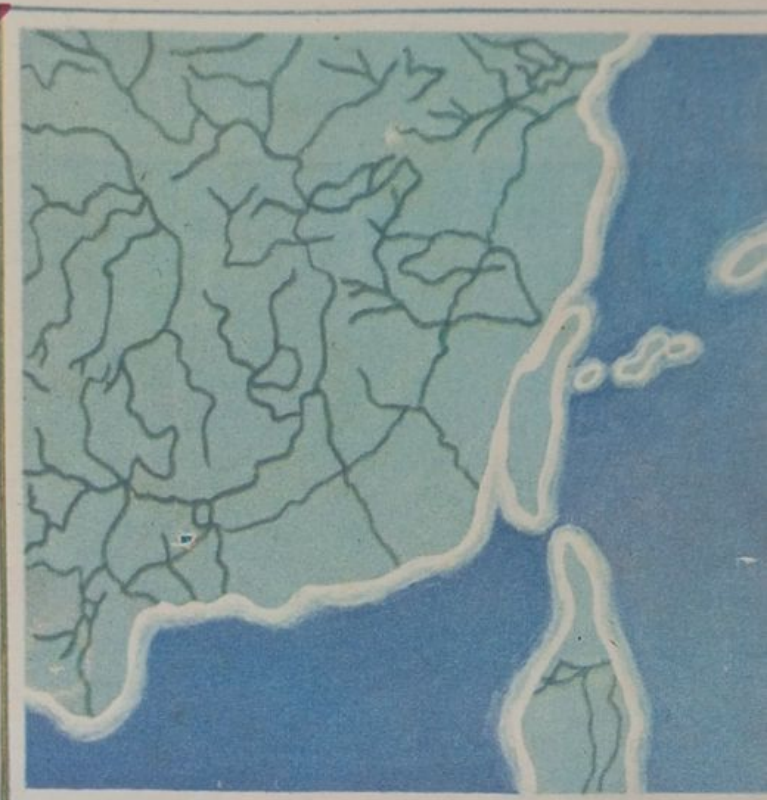
ABOVE: The rise of the sea level during the Holocene. The sea level was lower 9000 years ago. A world-wide rise accompanied the melting of glaciers.



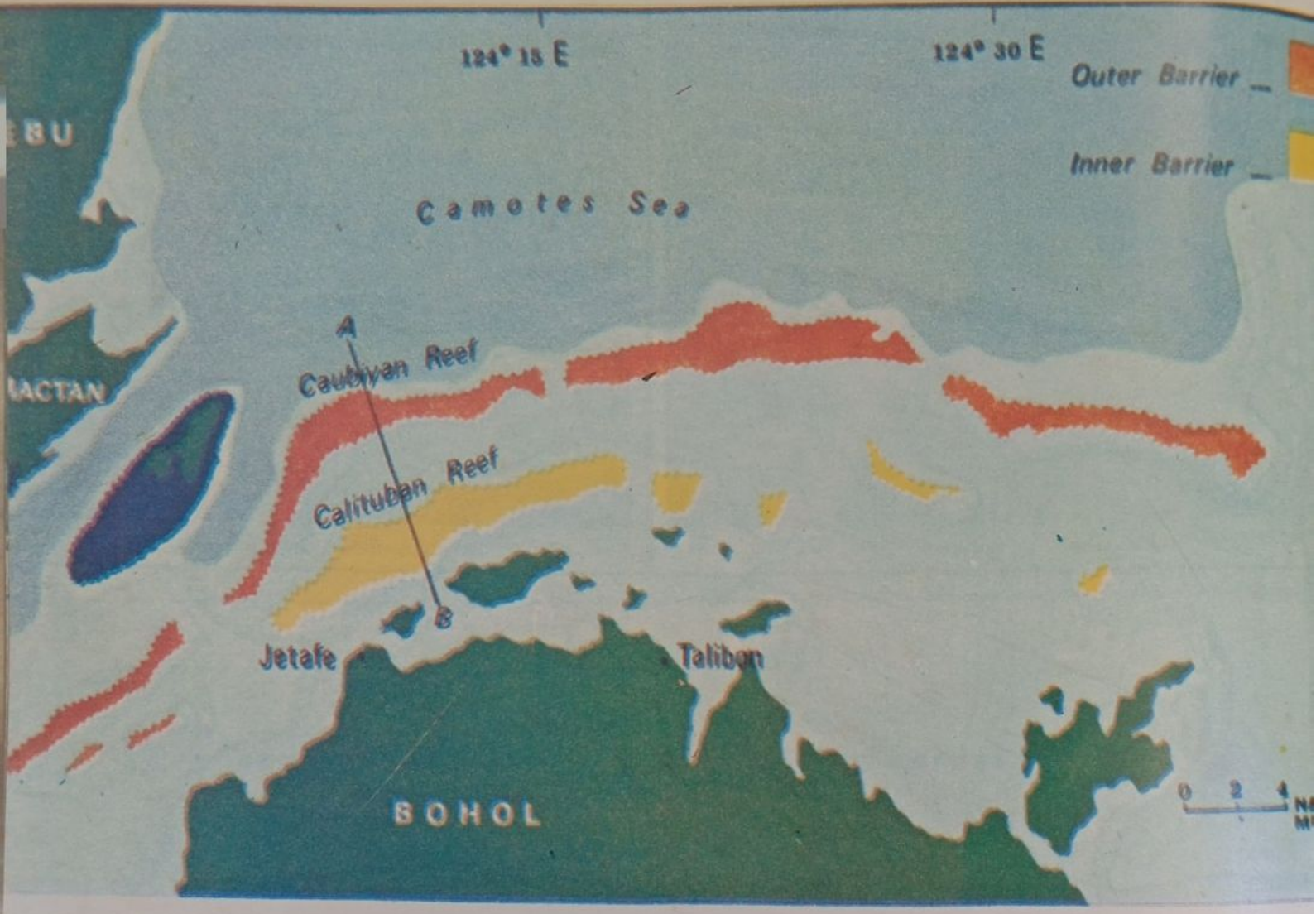
Paleogeographic Maps of Northern Luzon and China during the Pleistocene (after C. C. Lin 1963)

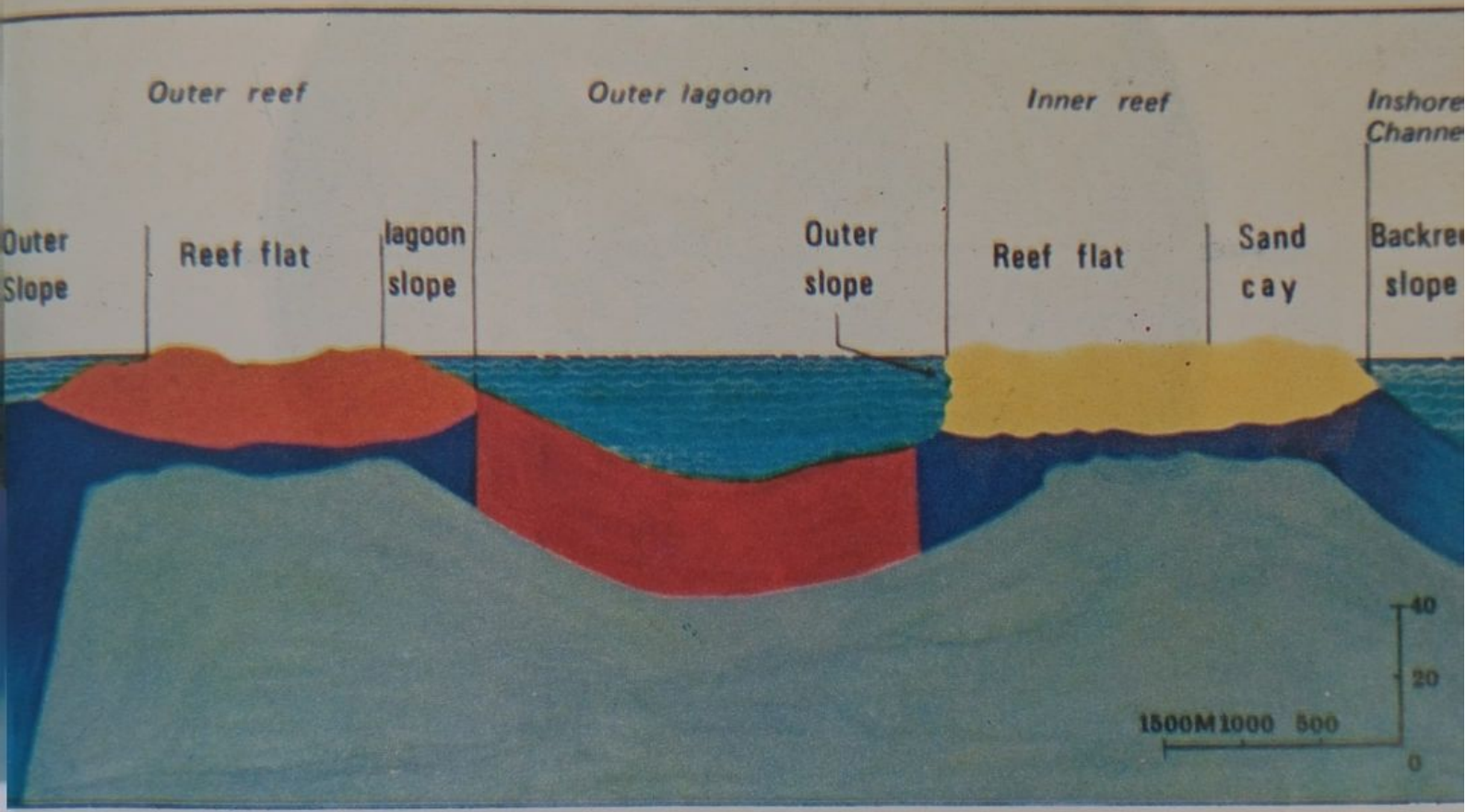


MINDEL GLACIAL



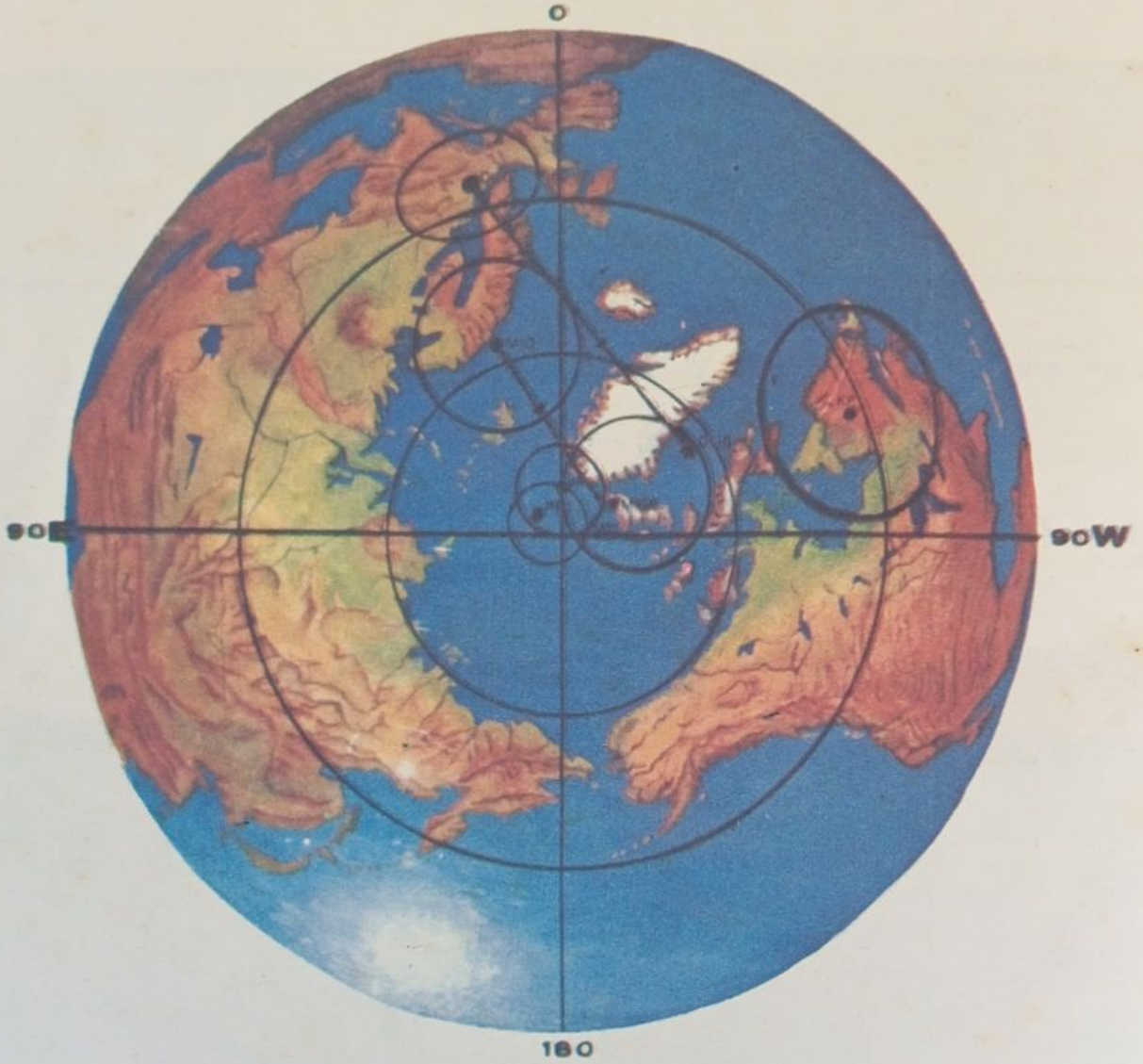
MINDEL-RISS INTERGLACIAL


124° 15 E
124° 30 E
Outer Barrier
Inner Barrier
Camotes Sea
EBU
MACTAN
A
Caubiyan Reef
Calitubban Reef
B
Jetafe
Talibon
BOHOL
0 2 4



LEFT: The Double Barrier Reef of Bohol.

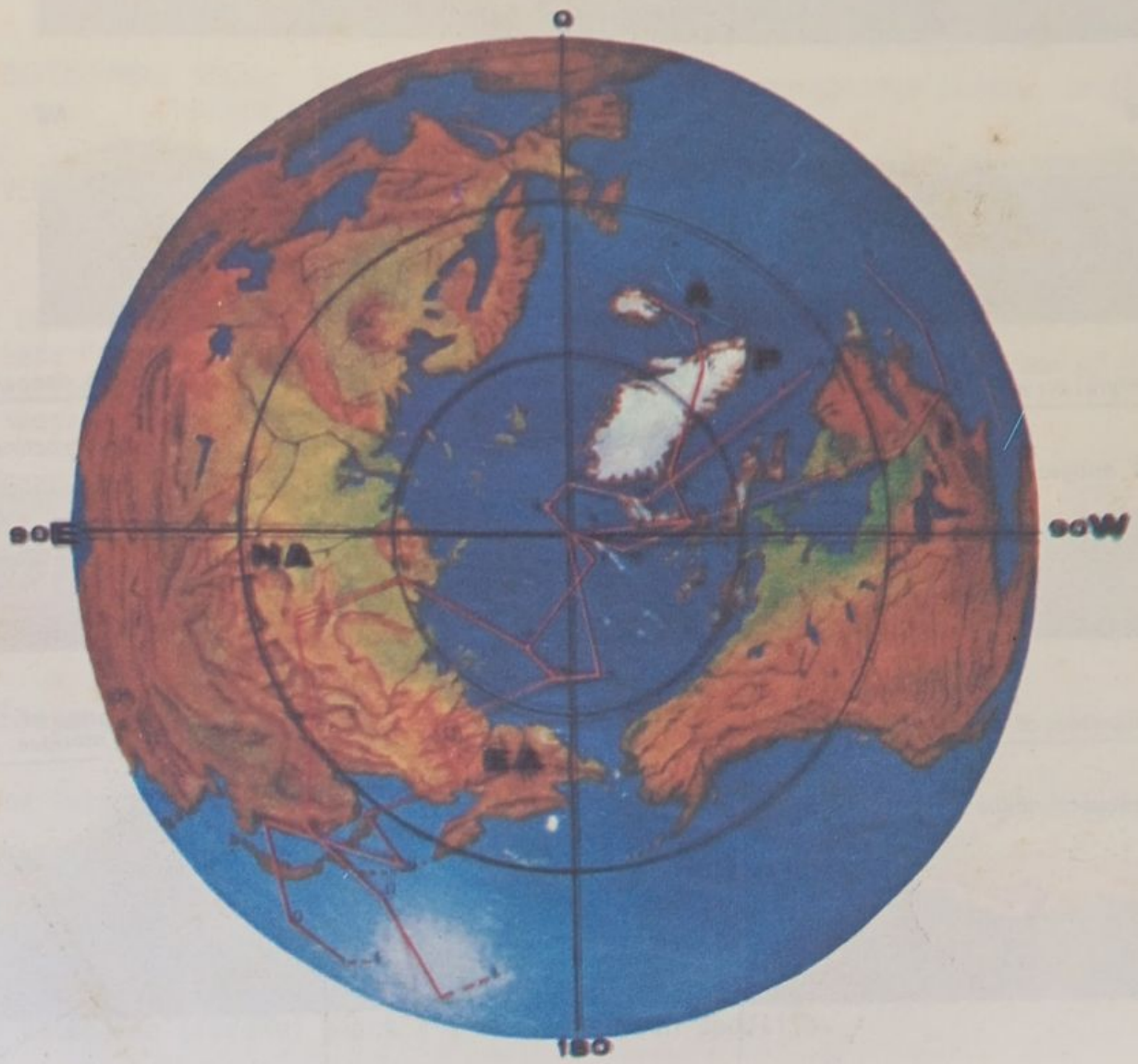
ABOVE: Cross section of the Double Barrier Reef of Bohol.

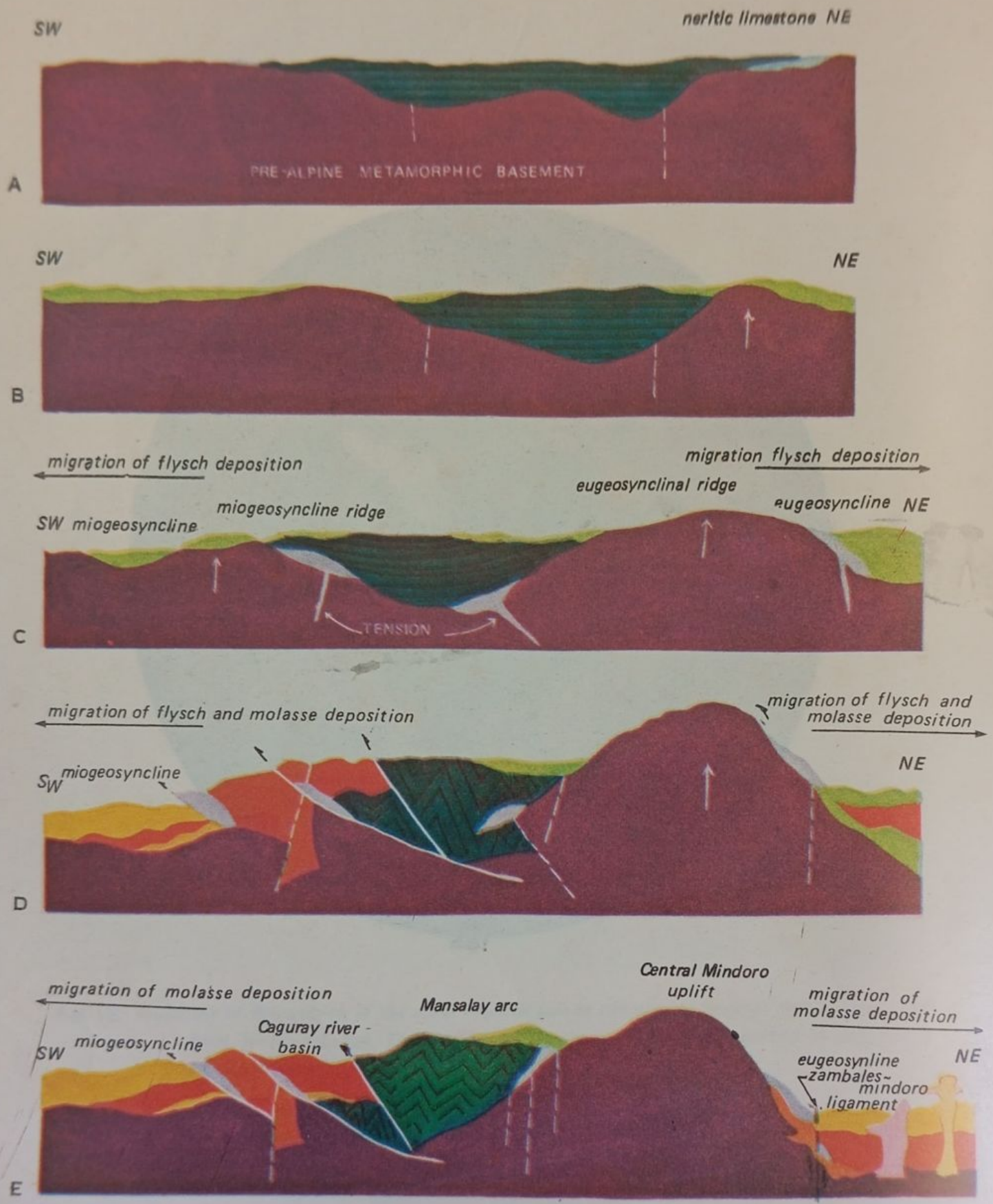


ABOVE: Projection of the position of the north magnetic pole as indicated by igneous rocks of various ages from Northern Luzon. The diagram shows how the poles have wandered through time as recorded in Philippine rocks.

Rec	–	*Recent*
Mio	–	*Miocene*
KP	–	*Critaceous – Paleogene*
PP	–	*Plio – Pleistocene*
Olig.	–	*Oligocene*

RIGHT: Polar Wandering curves of the Philippines (P) North America (N.A.), Australia (A), India (I) Eurasia (EA) are indicated by red curves. These show the apparent position of the North Pole during past geologic times. The curve for the Philippines is closely related to the curves for Australia and India.


0
90E
90W
NA
SA
180



These diagrams illustrate the complex geologic history of Southern Mindoro which involved the deposition of sediments on an ancient foundation of Paleozoic rocks uplift, folding, faulting, and volcanism.

SCHEMATIC SECTIONS SHOWING THE EVOLUTIONARY PATTERN OF SOUTHERN MINDORO GEOSYNCLINE

EVOLUTIONARY STAGES:

A- GENERATIVE STAGE: Late Paleozoic-Jurassic. Embryonic downbuckling of the miogeosynclinal-type furrow. Deposition of Mansalay Formation.

B- INITIAL DEVELOPMENT STAGE: Early Cretaceous. Arkose-chert-spilite stage. Initial uplift of the basement rocks.

C- FINAL DEVELOPMENT STAGE: Late Cretaceous-Early Paleogene. Ophiolitic magmatism with later flysch filling of the geosyncline. Upbuckling of the Mansalay Formation.

D- OROGENIC OR TERMINAL STAGE:
1.) Late Paleogene keratophyric- andesitic volcanism; thence upthrusting of the eugeosynclinal-type black shales in the hinterland.
2.) Neogene miogeosynclinal- type molasse deposition.

E- POST-GEOSYNCLINAL PERIOD; Late Neogene-Pleistocene. Completion of molasse deposition. Intrusions of diorite and related hypabyssal bodies. Terminal volcanic activity mostly vent eruptives and lava flows. Positive and negative vertical movements.

-Late Neogene-Pleistocene vent volcanics and lava flows.

-Neogene Intrusives (Diorite, etc.)

-Neogene molasse deposits

-Late Paleogene (Oligocene) Keratophyric and (or) andesitic flowrocks

-Early Paleogene (Eocene) black shales and flysch deposits

-Late Cretaceous-Paleogene serpentinized ultrabasic rocks

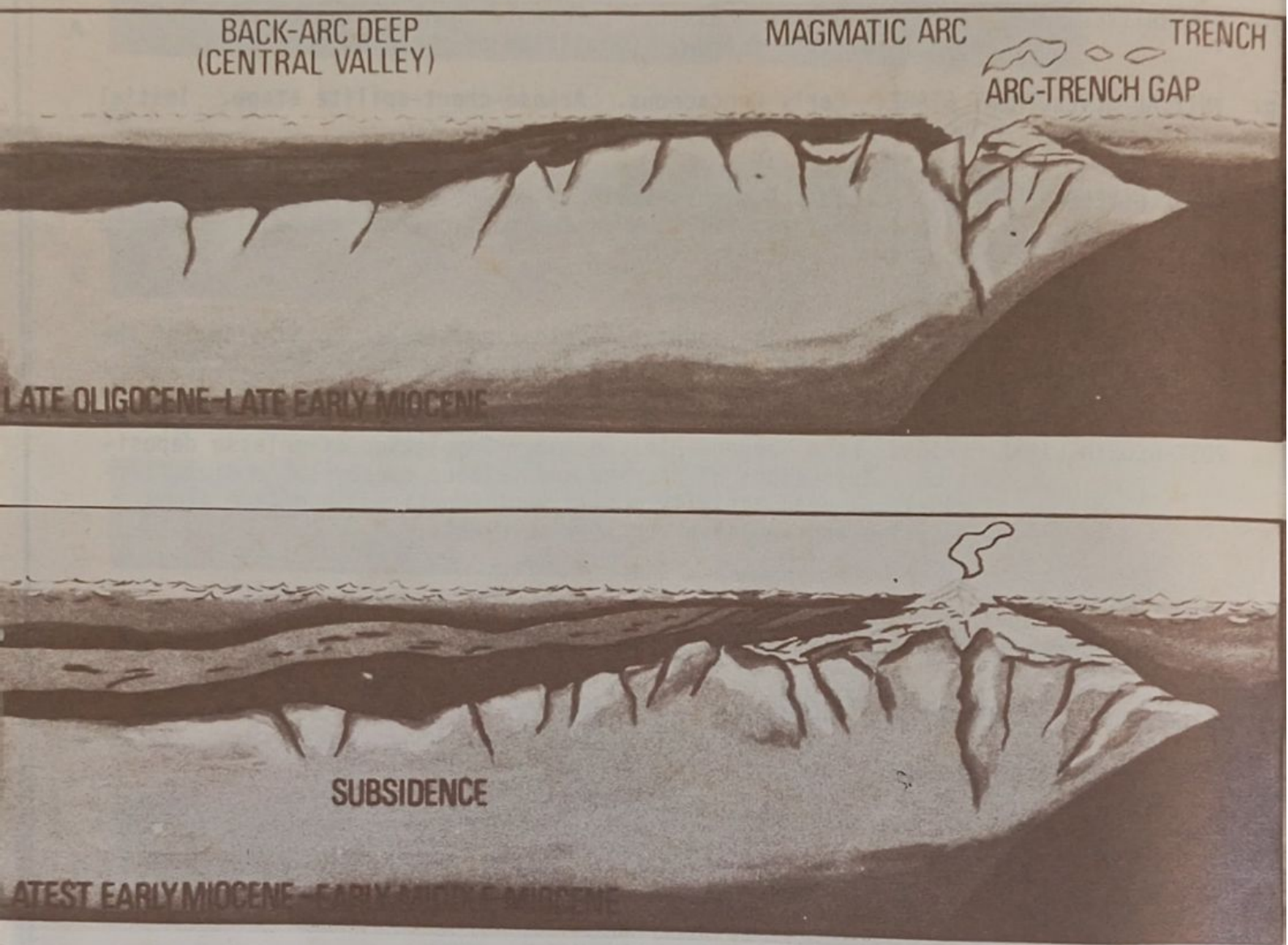
-Early Cretaceous-Paleogene rocks: 1. Arkose; 2.Chert-spilite

-Jurassic clastic suite (Mansalay Formation)

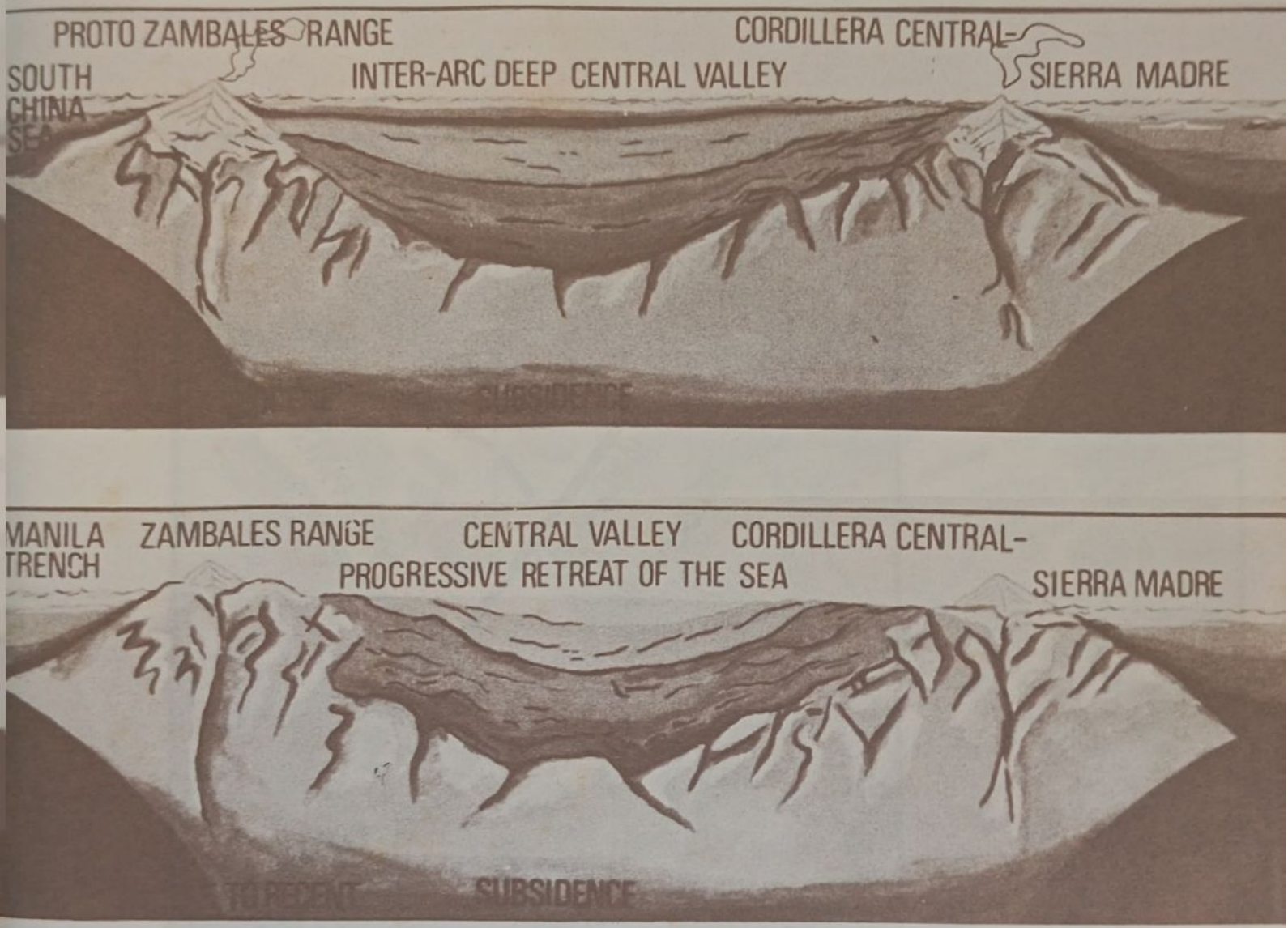
-Middle-Late Paleozoic Mindoro Metamorphics

-Imbricate thrust structure

-High angle fault


BACK-ARC DEEP
(CENTRAL VALLEY)
MAGMATIC ARC
TRENCH
ARC-TRENCH GAP
LATE OLIGOCENE–LATE EARLY MIOCENE

SUBSIDENCE
ATEST EARLY MIOCENE



LEFT AND ABOVE:

Cross sections showing the Geologic Evolution of Luzon Central Valley according to Beicip (1977)

A – About 30 MILLION YEARS AGO, a volcanic chain along the present day location of Sierra Madre developed. To the west marine sediments started to accumulate in the Central Valley basin on top of older rocks.

B – Subsidence persisted during the next 10 million years. The sedimentary deposits became thicker.

C – About 15 million years ago, the Zambales range developed west of the central valley basin.

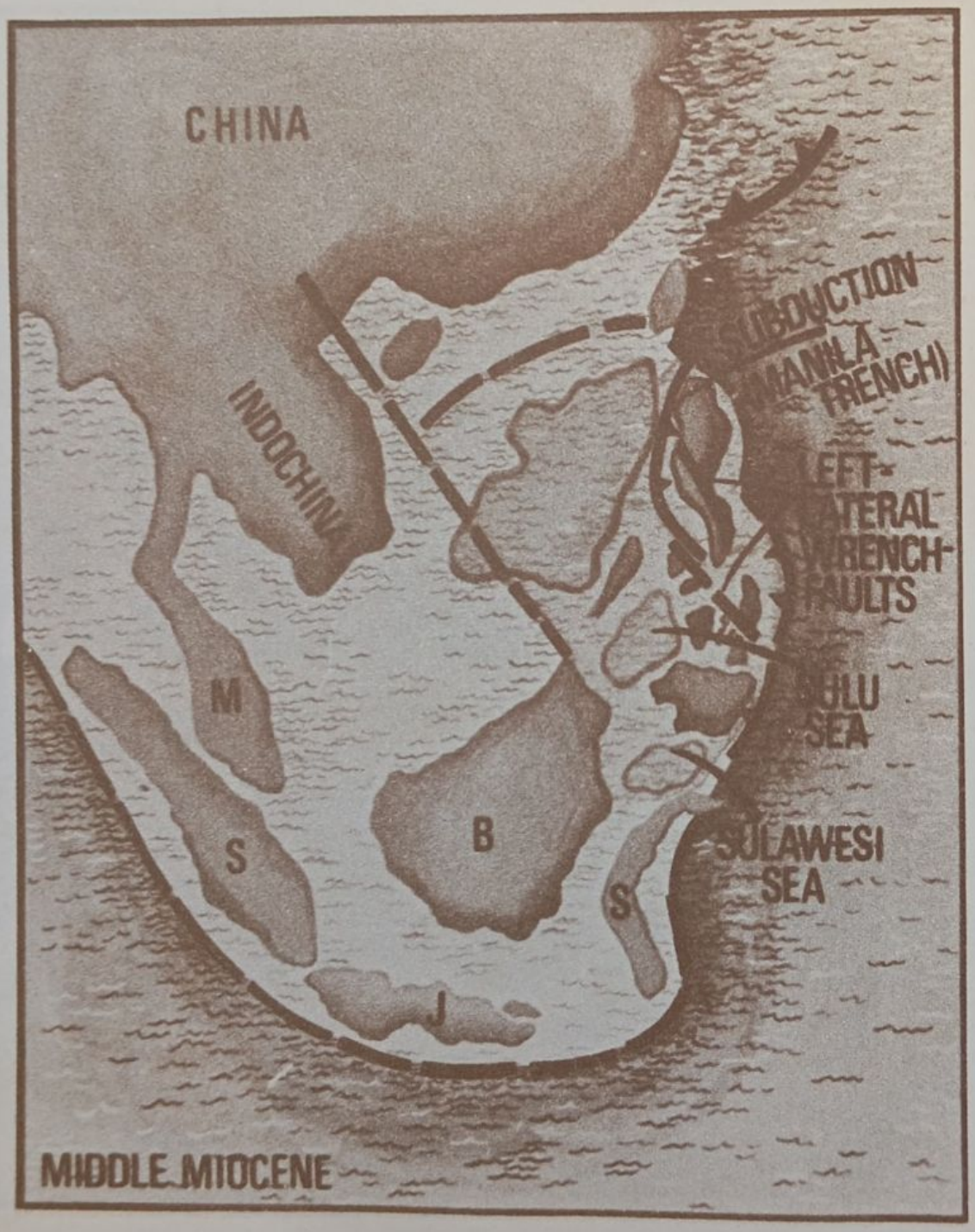
D – As the sea retreated during the last million years, the Central Plain of Luzon became land.

Plate Tectonic reconstruction of SE Asia according to Audley-Charles (1976) and Beicip (1977)

CONTINENTAL CRUST

OCEANIC CRUST

PHILIPPINES ARC


CHINA
INDOCHINA
M
S
B
S
J
SULAWESI
SEA
MIDDLE MIOCENE

of the Mesozoic eon a great variety of plant life was flourishing in the Philippines. The dominance of the gymnosperm *Classopollis* associated with Auracaria and ferns shows similarity between Philippine and Australian flora in Mesozoic times. *Classopollis, Auracariacites australis,* and *Zonalapollenites dampieri,* found in the Palawan and Reed Bank wells, are also found in Ceylon and in Australia, both fragments of the supercontinent *Gondwana.* Thus the earliest rocks of the Philippines, found to have belonged to a continental environment, may also be fragments of Gondwana. Studies of ancient magnetism in Philippine rocks by Hsu, reported on in 1971, suggest that the Philippines, like Australia and India, had drifted northward beginning with Early Tertiary times. These studies will be discussed again later in this chapter.

Toward the end of the Mesozoic, a profound change in the crust underlying the Philippines affected the whole region and neighboring areas. The continental crust and land areas are submerged, while large volumes of volcanic rock are deposited on the seafloor. This episode extended to the Early Tertiary times (the Paleogene) and is identified by the ultramafic masses emplaced during the period beneath many areas of the Philippines. Upheavals during this period result in the injection of igneous bodies (plutons), such as those in Central Cebu, Negros, Panay, and Mindanao. The ultramafic areas contain chromite and nickel deposits; the plutons, richer in silica, contain large copper deposits. During this time, too, mangrove and beach forests containing nipa palms, *palomaria,* screw pine *(pandan),* climbing fern (*nito*) and fishtail palm fringe the land in many places. Inland, many lowland areas have dipterocarp forests. High elevations support trees of the lower montane forest and the mossy forest. Various algae thrive in shallow marine areas. In swamps, abundant vegetation exists, to be eventually converted into some of the coal now found in Polillo and Catanduanes. A varied topography exists even during early Tertiary times.

The framework of sedimentary basins is established toward the end of the Paleogene. Land surfaces exposed during the turbulent beginnings of the archipelago subside along troughs which eventually reach depths of thousands of meters in relation to present sea level. These severe deformations of the crust also raise certain areas by thousands of meters during the Neogene. In

this period, too, plutons are again emplaced along these areas of uplift that today constitute the magnificent mountain ranges in various parts of the archipelago and form the backbone of islands. Large amounts of sediment are eroded from these rising areas to fill existing troughs and form what are now the valleys of Northern Luzon, Central Panay, and Mindanao. Crustal deformation also results in the sliding past each other of large blocks along the Philippine fault. Numerous gold deposits develop in association with the Philippine fault. Most plutons injected during this period also contain rich deposits of copper; a few form iron deposits.

Abundant life thrives on the tropical islands and Philippine seas during the Neogene. Numerous molluscs inhabit Philippine shores along with crabs, sea urchins and even sharks. In the shallow portions of the seafloor, coral reefs analogous to those we see today fringing numerous islands or growing into atolls develop in the Miocene seas. These reefs with their abundant life and porous framework accumulate oil and gas through successive periods. Several of these reef complexes containing oil deposits have been discovered and are today the sites of productive oil wells in Palawan. Many swampy areas during the Neogene on the other hand slowly convert elements in them into coal, so that large deposits of this resource are found today in Southern Mindoro, Cebu, Zamboanga, Surigao, Albay, and Negros.

Uplift of sections of the earth is widespread at the end of the Neogene. The phenomenon exposes areas above the surface of the sea, to serve as land bridges on which plants grow and mammals, including man, could pass to and from these islands. Global climatic changes affect the level of the sea and the distribution of continental ice sheets. During times of glaciation, large amounts of seawater are drawn from the oceans and solidify into ice, depressing the sea level. Submarine ridges are exposed along with shelf areas around the Philippines. The latest glacial episode ended about 6000 years ago; since then, the sea level has risen and submerged large tracts of land around islands of the Philippines. Consequently, islands formerly connected are separated by shallow seas.

On the archipelagic landscape that is the home of the early Filipinos, in surroundings marked by forests of mangrove, nipa, rattan, bamboo, ferns and forests of dipterocarps, pines and grass-

lands, the Philippine Adam had such useful companions as elephants, rhinoceri, deer, boar, buffaloes, turtles, and clams. Bountiful food came from the seas, rivers, plains, and forests, and life flourished. Warm climate persisted here, in contrast to the North, where the glacial climate provided a harsh environment for living.

The complex history which the archipelago has undergone is specially reflected in some areas like Mindoro, where rocks of different ages are found. An interpretation of the geologic history of Southern Mindoro is summarized in the sections constructed by Rolando de Guzman in 1975 and reproduced here as the Plate entitled "Schematic sections showing the evolutionary pattern of Southern Mindoro Geosyncline."

A cycle of metamorphism produces a landmass which becomes the foundation upon which marine sediments — limestone and sandstones — are deposited. This happens during Late Paleozoic time. Deposition of sediments washed down from highlands in the north and northeast continues until the Jurassic as, gradually, the metamorphic basement subsides. Swamps and open marine conditions characterize the basin on which the sediments settle. Molluscs flourish in this ancient sea.

The next stage in the evolution of Southern Mindoro is marked by the upsurge of submarine volcanic rocks (spilite) along with the deposition of chert (a silica rock) and sandstones. This takes place during the Early Cretaceous, which commenced about 135 million years ago. The sandstones rich in quartz and feldspars are deposited along the margins of the basin. A suite of ultramafic rocks, spilite, and chert develops with the initial elevation of the margins of the basin. In the Early Tertiary, the subsiding basin is filled with products of erosion of the rising ridge — thick deposits of black shale, a fine-grained sedimentary rock consisting of silt and clay. Toward the end of the Eocene, sandstones, shales, and tuffs (deposits of ash from volcanoes) are deposited in Southern Mindoro.

A powerful movement of the earth brings the Central Mindoro Divide to great heights during Middle Miocene times, at the same time that a similar heave further north, in Zambales, raises the Zambales range. The uplift during the Miocene also results in the transformation of marine areas to land areas bordered by swamps. Other transitional areas, like Bulalacao, at the southern tip of Mindoro, and Semirara Island, further south, would be-

come sites of coal deposits. Erosion would strip older sediments from the uplifted areas during the Neogene. At this time, plutonic rocks are injected and during later stages, volcanism becomes the expression of the waning igneous activity.

After the Miocene and until the Quaternary, faulting and folding influence the formation of the rocks of Mindoro. The combination of erosion and earth movements gives rise to a varied topography on the island. In Semirara, submergence of the island during Late Miocene time results in the deposition of limestone. Toward the end of the Miocene or during the Early Pliocene, folding affects older rocks. Also during the Pliocene, there is a period of emergence followed by submergence. During the Quaternary, a gradual emergence of the island brings terrace gravel up to different parts of the island.

This fascinating rhythm of submergence, folding, uplift, and igneous activity is found in many other islands of the archipelago. The evolution of the Central Valley Basin of Luzon during the Cenozoic illustrates how troughs develop in many major islands. The illustration in the plates labelled "Cross sections showing the Geologic Evolution of Luzon Central Valley" is an interpretation of the history of the Central Valley of Luzon based on a plate tectonic model, as proposed by the geologists of BEICIP, a French petroleum institute.

The regional framework for the evolution of the Central Valley is depicted in the figure labelled "Plate tectonic reconstruction of Southeast Asia" with the Philippines considered part of the Asian continental plate's eastern margin up to Jurassic times. A fragment of the rim gradually shifts from the Asian continent during the Cretaceous with the opening of the South China Sea. This interpretation is an alternative to the suggestion that the Philippines is underlain by fragments of Gondwanaland, which was discussed earlier. Both interpretations, however, recognize an early continental episode in the evolution of the Philippine archipelago.

Geologists who studied Luzon in connection with the construction of the nuclear power plant in Bataan place the opening of the South China Sea at a later time, during the Oligocene.

They also adopt an interpretation of the geologic history of Luzon in terms of a plate tectonic framework. Their interpretation, however, incorporates ideas of Froilan Gervasio which define three stages in the development of the pre-Tertiary basement. During the first stage, in Gervasio's conception, a late Carboniferous event deforms, subjects to metamorphism, and uplifts an older sequence of volcanics, sedimentary and ultramafic rocks. Erosion of volcanic and continental material during the Permian creates debris which is later deposited as thick sequences of shales and sandstones. A late Permian event of mountain building subsequently deforms, metamorphoses, and uplifts these rocks. The pre-Jurassic basement complex is therefore the product of the Carboniferous and Permian episodes of mountain building. These construct land areas from which Jurassic and Cretaceous sedimentary rocks are derived. Interlayered with conglomerates, sandstones, and shales are basaltic lava flows indicating an increase of volcanic activity through time.

All these units are again subjected to deformation and uplift during the Early Tertiary. During this time ultramafic rocks are emplaced and basaltic lavas are generated. The geologists of the nuclear plant site relate these events to a northwest-southeast extension of the crust, partial melting of the crust and movements of the seafloor. During the Eocene, lava flows develop and quartz diorite intrusives are formed in Southern Luzon. The pushing of the seafloor underneath the crust of the Philippines from the east results in the construction of a volcanic arc along Sierra Madre.

Rocks formed before and during Early Tertiary times therefore comprise the foundations upon which younger rocks are deposited in the Central Valley and other areas of Luzon (and the Philippines in general). Submergence of the Central Valley begins in the Late Oligocene and produces deposition of marine shales and sandstones. Limestone is deposited along the Sierra Madre. Volcanism during the Early Miocene also supplies materials that form part of the rocks filling the basin, which deepens toward the west.

Another major advance of the sea starts during the later part of the Early Miocene — carbonate rocks are deposited on a platform along the northern and northeastern rim of the Central Valley Basin of Luzon. During the early part of the Middle

Miocene, volcanic activity forms islands with surrounding tidal flats. The Zambales Range also starts to emerge, making a new stage in the development of the basin. Unlike earlier times, when most of the sediments came from the east and the north, in the early Middle Miocene a new source now supplies the basin with the debris of erosion. The rise of the range also creates a barrier which isolates the basin from the sea. A new volcanic arc in the western part of the basin develops along a zone plunging eastward where the oceanic floor of South China is pushed beneath the crust of Luzon, in what is called a subduction zone.

Quartz diorite intrusives are emplaced during the Miocene. Numerous episodes of local and regional uplift form land areas and produce gaps in the record of sedimentary rocks. During the Middle Miocene, another cycle of transgression develops small reefs in the Central Valley. Tidal flats are periodically submerged by debris rushing from the sides of steep mountains existing in the Middle Miocene. Small deltas form where rivers flow into the marine waters of the basin, now flanked by two mountain ranges — in the east and the west — and by the Central Cordillera in the north.

Another uplift in Late Miocene times again covers tidal flats with deltas. Since the central portion of the basin is thus filled, it could hardly be influenced by open marine conditions. The amount of debris caused by erosion decreases during Late Miocene and Early Pliocene times, so that tidal flats again begin to form. Volcanism persists in the adjoining Zambales range. A brief period of marine transgression ends with uplift and folding which affect the whole basin during the Late Pliocene. The sea retreats and is replaced by flood plain deposits and alluvium. During this time, the site in which subduction takes place shifts from a trough bordering West Luzon to the present location of the Manila Trench. An eastward migration of volcanic centers accompanies this shift in subduction.

During the Quaternary, faults displace rocks in the area on account of an east-west compression. A new cycle of volcanism spreads a mantle of tuffs over the Central Plain and the area now occupied by Metro Manila. Volcanic plugs pierce through the rocks filling the basin. Alluvial and flood plains develop once more, to remain until the present.

The complex history of sedimentation, submergence, folding, metamorphism, igneous activity, uplift, and erosion is reflected in other areas of the Philippine archipelago. It is perceptible, for instance, in various geologic cross-sections from north to south — along Ilocos Norte, across the Cagayan Valley, across Panay in the central part of the Philippines, and across Mindanao. All through the archipelago, a common history may generally be discerned. An old basement terrain with metamorphic rocks may be observed underlying Cretaceous and younger rocks. This is significant in view of the fact that increased volcanism occurs, and the archipelagic environment begins in the Cretaceous, during which most areas are subjected to deformations of the crust, giving rise to troughs and mountain chains Deformations also result in faults, and movements along these faults have contributed to the island and sea topography of the archipelago.

The complex geologic conditions during the Cenozoic are also perceptible today in the wide variation of rock units to be found in the Philippines. The sequence of the formation of rocks representing different geologic periods is summarized in a chart prepared by Wataru Hashimoto and Guillermo Balce in 1976. The chart shows a wide gap between Oligocene and older rocks in many areas of the Philippines. This is consistent with the areas where erosion and non-deposition occurred. Another wide gap may also be observed between Miocene and Pliocene rocks, a gap also found in offshore areas in Palawan where oil wells had been drilled. Many areas also show a similar break between Pliocene and Quaternary rocks. In addition to the episodes of widespread uplift causing these gaps, the chart also shows breaks of local origin in the record of rocks. Deformation of the crust therefore resulted in the specific uplift of some parts and corresponding submergence of other parts of the archipelago. The chart also shows radioactive dates established for some igneous rocks.

The varied environments and geologic conditions in the Philippine archipelago during the Cenozoic make it difficult to determine correlations between one major island and another, or between one basin and another. However, marine fossils have been useful in demonstrating the chronological position of sedimentary rocks. The assemblages of foraminifera recognized in the Philippines are shown in the Table on page 174.

PERIOD				PLANKTONIC FORAMINIFERAL ZONES RECOGNIZED IN THE PHILIPPINES
QUATERN.	HOLOC.			
	PLEIS.			*Globorotalia truncatulinoides Z.*
TERTIARY	PLIOCENE		N21	
		2		*Globorotalia tosaensis Z.*
			N20	*Pulleniatina obliquiloculata Z.*
		h		
			N19	*Sphaeroidinella dehiscens dehiscens Z.*
		1		
			N18	
	MIOCENE		N17	
		g	N16	*Globorotalia menardii Z.*
			N15	
		3	N14	*Globorotalia mayeri Z*
			N13	
			N12	*Globorotalia fohsi lobata Z.*
		f		
		2		*Globorotalia fohsi Z.* *fos*
		1		*Globorotalia peripheroronda Z.*
				Orbulina Datum
			N9	
	OLIGOCENE			*Globigerinoides sicanus/Globigerinatella insueta*
				sic *ins*
		5		*Globoquadrina "rohri" Z.*
				Globigerinoides Datum
			N4	*Catapsydrax Z.* *cat*
		4	N3	*Globigerina ciperoensis Z.*
			N2	*(Globigerina opima opima Z.)*
		1	N1	*(Globigerina ampliapertura Z.)*
		d		
		c	P18	
	EOCENE		P17	*Hantkenina alabamensis Z.*
		b	P16	*(Globorotalia cerroazulensis Z.)*
			P15	
			P14	
		3		
			P10	
			P9	
		a 2		*Globorotalia velascoensis Z.*
			P5	
	PALEO	1	P1	
CRETACEOUS	Upper			*Globotruncana stuarti Z.*
				Globotruncana concavata Z.
	Lower			*Globotruncana helvetica-*
				Globotruncana schneegansi Z.

Planktonic foraminiferal zones recognized in the Philippines
(Adapted from Hashimoto and Balce, 1977)

These detailed studies of fossils and rocks in the islands of the Philippines and offshore areas contribute to a better understanding of the complex geology and prehistory of the Philippines. No less complex is the evolution of the lands and seas of New Guinea and other Southeast Asian neighbors of the archipelago, so that a precise correlation of rocks based on their fossils and on radioactive dating would allow earth scientists studying the region to discover the relationships of events which occurred across national boundaries of Southeast Asia's present-day archipelagic environment.

The evolution of the archipelagic environment of island arcs such as the Philippines and Indonesia may be variously interpreted in terms of different theories of crustal movements and mountain building. The most successful theory thus far is based on plate tectonics. This theory was mentioned earlier in the Introduction to this book. It will be recalled that under this concept the outer shell of the earth, the lithosphere, consists of rigid slabs known as plates. These plates overlie a plastic, more flexible interior known as the asthenosphere. The plates of the lithosphere are generated in zones of divergence such as are found in ridges in the middle of the world's oceans. The new plate material formed in these zones pushes away elements previously formed. The motion of the plates is believed caused by convection currents in the plastic interior of the earth, which is extremely hot on account of small amounts of radioactive material and of the residue of high temperatures from the early stages of the formation of the earth. Heat is transferred from the interior and stability maintained by means of convection, the swirling movement of hot fluids. It takes place in the atmosphere and gives rise to winds. In rocks, the movement is exceedingly slow, but it definitely takes place in the molten core of the earth and gives rise to the earth's magnetic field. It could also be present in the solid shell known as the mantle, located below the mantle. Diverging convection currents would therefore explain why new material is introduced to the crust along oceanic ridges.

Plates converge along subduction zones, and evidence of this process may be found in trenches. In these subduction zones, one plate is pushed under another. Thus it is believed that the Philippine Sea Plate to the east converges with the Eurasian Plate along the Philippine trench. West of Manila, the Manila

trench is another subduction zone, with the South China Sea pushed under the crust of the Philippine archipelago. In these zones then plates collide and cause crustal deformation, which in turn results in the folding of rocks. Earthquakes therefore take place along these zones. As the cold lithospheric plate is pushed into the hot interior, it heats up. This heating up, also partly caused by friction between the plates, melts some parts of the plate; hence, the lava and volcanoes that constitute island arcs are closely related to earthquakes and trenches.

The deformation of the crust resulting from the collisions of plates could give rise to mountain ranges and troughs such as may be seen today in the Philippines. Behind the belt of mountain ranges, these zones of crust form marginal seas, like the Sulu Sea and the South China Sea. In the mountainous areas, erosion is rapid and the debris accumulates in the troughs. Downward movements of the crust also heat up the sedimentary filling of basins and convert the loose materials into meamosphic rocks Further heating melts some of the rocks and again forms the silicate melt known as magma. This is generally richer in silica, and during episodes of deformation the magma is introduced to higher levels of the crust and there solidifies as intrusive rocks. Analyses of isotopes in Philippine intrusive rocks, however, show that the few intrusives studied are closely related to the oceanic crust. This means that the magma that formed the intrusive rocks was probably derived from the melting of the oceanic plate.

Crustal movements along the zone of collision also send up rocks formed at great depths. These rocks are richer in iron and magnesium, the ultramafic rocks. As may be recalled, these rocks closely resemble the material of which the mantle is believed built. Ultramafic belts existing in the Philippines may be used to determine the sites of ancient trenches. The subduction zone also brings together different rocks to constitute a *melange*, from the French for mixture. In Antique, such a melangem ay be present. Dr. Luis Santos Yñigo in 1956 reported that boulders of glaucophane schist or blueschist are associated with othe rocks. Glaucophane is a blue mineral formed at high pressures and relatively low temperatures, conditions which are difficult to achieve except under the postulated situation of cold lithospheric plates descending into the hot interior in subduction zones.

When downward subduction movements cease, they would leave a considerable amount of lighter material, such as sediments and the oceanic crust, surrounded by denser material from the mantle. An upward movement is necessary to restore equilibrium; this is another mechanism which has created magnificent mountain ranges, such as the Himalayas and the Andes. Subduction is still active today in the Philippines. Young sediments in basins have not yet been deformed. They remain buried and are continually being covered. It may therefore be said that the Philippine archipelago, in the cycle of mountain building, has not yet achieved its maximum development. The remark of the noted scientist John Katili in 1971 that Indonesia is "a mountain belt in statu nascendi" may be equally true of the Philippines.

The theory of plate tectonics also explains satisfactorily the hypothesis that continents have drifted apart. As pointed out earlier, there is considerable evidence supporting the possibility that the Philippines, Australia, and India were part of Gondwanaland. Other scientists, such as M. F. Ridd, the Tarlings, and S. K. Acharyya, have also suggested that Southeast Asia was part of this supercontinent. Changes in the patterns of convection in the interior may have led to the fragmentation of the supercontinent, after which the fragments were carried off in different directions, with the plates serving as rafts.

Studies on the ancient magnetism of rocks help in analyzing the motions of the plates. Rocks contain magnetic minerals, such as magnetite, the mineral that forms Lodestone. At high temperatures, materials lose their magnetism because ferro-magnetic atoms such as iron are knocked around indiscriminately instead of being systematically arranged in the crystal structure. Upon cooling, the atoms are arranged once more and the magnetism of the material again becomes oriented parallel to the prevailing field. Igneous rocks therefore may serve as compasses to indicate the direction of the ancient magnetic field of the earth. Studies of ancient magnetism have shown that the earth's magnetic poles have shifted in relation to the crust, and that the poles in different continents have moved along varying paths. The movement of the poles, traced by means of polar wandering curves as recorded in rocks, has been used to support the theory of continental drift and in reconstructing the ancient positions of continents. Since it is also an established fact that magnetic patterns are formed parallel to oceanic ridges, such patterns as

recorded in rocks mark episodes of polar reversals. An analysis of the patterns helped in the study of the development of the Philippine Sea Plate, as discussed in the preceding chapter.

As mentioned earlier, I-Chi Hsu studied the ancient magnetism of Tertiary rocks in Luzon and Marinduque. The results of his study are reproduced in the diagrams here, which show that Pleistocene rocks had a north magnetic pole essentially coincident with the present-day magnetic north pole. As one goes back into the past, the deviations increase. The position of the pole indicates a northward movement of the Philippines, which is to say that Luzon at some point in the distant past was located south of its present position.

The pattern of the polar wandering curve of the Philippines shows that it follows that of movements related to India and Australia. It is markedly different from the patterns established for other parts of the world, such as Eurasia and North America. Because of this, Hsu concluded that the tectonic development of the Philippines resembles that of Australia and India. The floral evidence from shore exploration in Palawan further confirms this and supports the suggestion that early Philippine prehistory involved a continental stage, during which the archipelago was part of such vast mass of land as Gondwana. This geographic condition persisted up to the Jurassic until further fragmentation brought the Philippines to its archipelagic stage in the Early Cretaceous. A major rearrangement of the plates took place in the Early Tertiary. The imprint of this important event is found in the metamorphic belt along the east coast of the Philippines and in the Paleogene intrusives. The magnetic patterns of plate motion in the Philippine Sea also record the development of the Philippine Sea during the Paleogene and the Neogene.

Among other places in Southeast Asia, the Philippines is in a unique position because it is affected by three major plates — the Eurasian, the Australian, and the Philippine Sea. The convergence of these three plates adds more convolutions to theb asically complex conditions along plate margins which, however, pertain to a situation that must have existed since Neogene times and perhaps even earlier. A proper unravelling of the prehistory of the Philippines before the archipelagic stage must take into account its continental beginnings.

Studies of Philippine archaeology and anthropology show that man was in the Philippines in the Pleistocene. During that time, the Philippines had many plants similar to the present-day flora, but there were animals that are extinct today. The geography and geology of the archipelagic environment were similar in many ways to those of the Philippines today, though glacial episodes may have turned the climate slightly colder. Present-day offshore areas were exposed so that many islands of the Philippines were connected with each other and with lands which are now part of neighboring countries. An interchange of animals, plants, and culture was facilitated during these periods of low sea level.

Any number of life forms in the Philippines may have persisted from earlier times, especially certain primitive plants and animals. If this is correct, some may be survivors of the breakup of Gondwanaland, which means that they existed during the continental stage of the Philippines. During the Early Tertiary, Southeast Asia had connections with Eurasia, as shown by the presence in Eurasia of tethyn plants that obviously migrated from Southeast Asia. Some remnants of the flora of Southeast Asia are found today in the Middle East.

Philippine culture therefore evolved in a milieu containing elements that we see today — an island and sea network, tropical climate, lush flora and fauna, volcanoes, mountain ranges, and earthquakes. The world view of the early Filipinos was shaped by this environment, and myths that have reached us by oral tradition, such as those narrated in Part II of this Volume, are expressions of this view. Political organization, as it is possible to recall it today, evolved in response to the archipelagic environment of the Philippines. Suitable terrain along bodies of water drew men to form settlements; dense jungles and mountain ranges discouraged mobility.

It is not yet clear whether some parts of the Philippines originated from the Pacific, but some conditions seems to indicate that this is possible. The Parece Varela ridge is a center of seafloor spreading or plate divergence. In the Marianas, schists are present, indicating that this island arc has a complex evolution. If the continental material in the East coast of the Philippines is originally from the Pacific, that area would correspond to the legendary land of Lemuria, the analogue of the legendary land of Atlantis in the Pacific.

This journey into the past beyond the written and cultural records of man is an attempt to discover how environments evolved, how the configurations of lands change with time, how land masses could possibly shift with respect to one another. We see fragments of mountain ranges which are pitiable remains of once lofty and magnificent handiworks of nature. The dynamic crust of the Philippines has by turns risen and fallen. Islands today are surface expressions of the underlying complex structure. Today, processes that took place in the distant past provide Filipinos and other people benefits in the form of priceless earth resources. As a result of past geologic processes, the Philippines has become a vast treasure house of gold, copper, nickel, and chromite. Geothermal energy abounds because of the location of the Philippines in the circum-Pacific Belt of Fire. Coal, already known to be abundant, will be a source of comfort in the face of widespread anxiety over the persistent fuel crisis. Oil from ancient rocks, found through continuing explorations of sedimentary basins of the Philippines, is expected to fill much, perhaps eventually all, of the nation's needs.

The geological conditions of the Philippines make it susceptible to earthquakes and volcanic eruptions. Annual typhoons will persist. National development plans will therefore have to reckon with these hazards in the future. Technological advances in the fields of earthquake prediction and prediction of volcanic eruptions will be depended upon to mitigate destruction.

The next million years will probably see the Philippines moving on through its cycle of mountain building. Eventually, the mountain belt may be fully developed. Through an episode of mountain building, metamorphism may again convert the archipelago into a continental environment.

As they stride on to the unknown, Filipinos today and future generations will do well to keep on unravelling the past. A better understanding of the nation's past geological history will help in the search for more earth resources and provide counsel in the construction of important and delicate infrastructure projects, such as dams. The inevitable increase in population through the years obviously necessitates knowledge and ability to make maximum use of essential resources, much of which are still locked in the depths of the earth.

The Philippine environment is the stage on which the first Filipinos appeared. More intense effort to rediscover this and other ancient environments may reward studies of Philippine anthropology and archaeology with greater understanding of the forces and elements that molded man's nature and the Filipino identity. It is wise to keep in mind that a prelude of hundreds of millions of years preceded the raising of the curtain to the drama of Philippine history.

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The evolution of the universe, galaxies, stars, the solar system and the earth is traced for the lay reader by Lloyd Motz in *The Universe—Its Beginning and End* (London: 1976). The fascinating subject of the genesis on the universe is also presented by Steven Weinberg *The First Three Minutes* (New York: 1977), a book written for the general public such as "a smart old attorney who does not speak my language, but who expects nonetheless to hear some convincing arguments before he makes up his mind," as explained by Dr. Weinberg in his preface to the book. Further readings in cosmology are suggested in an annotated bibliography in *The First Three Minutes*. The interested reader may also consult the following more technical papers on astronomy which have appeared recently: Margaret J. Geller "Large-Scale Structures in the Universe," *American Scientist*, LXVI:2 (March-April, 1978), 176-184; Richard B. Larson, "The Origin of Galaxies," *American Scientist*, LXV:2 (March-April 1977), 188-196; Stephen E. Strom and Karen M. Strom, "The Evolution of Disk Galaxies," *Scientific American*, CCXL:4 (April, 1979), 556-566. The awesome environment of black holes is discussed by Larry L. Smarr, "Our Elastic Spacetime: Black Holes and Gravitational Waves," *American Scientist*, LXVI:1 (January-February, 1978), 72-79. Speculations on the early evolution of the earth, separation of the core, mantle and crust which deserve close attention are presented by Francis Birch in his Presidential Address "Speculations on the Earth's Thermal History," *Geol. Soc. American Bulletin*, LXXVI:2 (February, 1965), 133-154. An appreciation of the vast time span involved in the evolution of the universe, the solar system, the earth, its oceans and atmosphere and life, can be found in the *Dragons of Elen-Speculation on the Evolution of Human Intelligence* (New York: 1977) by Carl Sagan. Dr. Sagan compressed the 15 billion years span since the Big Bang into a single year such that the Paleozoic era, in this cosmic calendar, would begin on December 17, the Cretaceous on December 28, and the first human beings appear only on December 31. Recorded history occupies only the last 10 seconds of the calendar which began with the Big Bang on January 1.

Elso S. Barghoorn and J. William Schopf describe early traces of life in "Microorganisms Three Billion Years Old from the Precambrian of Africa," *Science*, CLII:3723 (May 6, 1966), 759-763. Multicellular organisms from the Precambrian are also reported in an earlier paper by Elso S. Barghoorn and Stanley A. Tyler, "Microorganisms from the Gunflint

Chert," *Science*, CXLVII:3658 (February 5, 1965), 563-577. The role of early plant life in the evolution of the atmosphere and further evolution of life is discussed in a paper which originally appeared in September 1970, by Preston Cloud and Aharon Gibor, "The Oxygen Cycle," *Chemistry in the Environment—Readings from Scientific American* (San Francisco: 1973). More advanced forms of Precambrian life is described in Martin Glaessner and Brian Daily, "The Geology and Late Precambrian Fauna of the Ediacara Fossil Reserve," *South Australian Mus. Rec.*, XIII:3 (1959) 369-401. The oldest metazoan fossils in North America are described in Preston Clowd, James Wright and Lynn Gloyer III, "Traces of Animal Life from 620 Million Year-Old Rocks in North Carolina," *American Scientist*, LXIV:4 (July-August 1976), 396-400. The fauna is compared with other localities where metazoa of comparable age have been found. Details on invertebrate fossils can be found in Robert R. Shrock and William Twenhofel, *Principles of Invertebrate Paleontology* (New York: 1953).

An attempt to reconstruct the unfamiliar face of the Paleozoic world presented by Richard K. Bambach, Cristopher R. Scotese and Alfred M. Ziegler in a paper which appeared recently, "Before Pangea: The Geographies of the Paleozoic World," *American Scientist*, LXVIII:1 (January-February 1980), 26-38. The geographies of later eras are reconstructed in A. G. Smith and J. C. Briden, *Mesozoic and Cenozoic Paleo-continental Maps* (Cambridge: 1977). A detailed study of conditions during the Jurassic is found in A. Hallam, *Jurassic Environments* (Cambridge: 1975). The possible position of Southeast Asia before the break-up of Gondwanaland is presented by M. F. Ridd, "Southeast Asia as a Part of Gondwanaland," *Nature*, CCXXXIV:5331 (Dec. 31, 1971), 531-533. Unlike most reconstructions, Don H. Tarling and Maureen P. Tarling show in *Continental Drift* (Aylesbury: 1977) the position of Southeast Asia relative to the ancient position of the continents. S. K. Acharyya places Southeast Asia in juxtaposition with Gondwanaland in "Mobile Belts of the Burma-Malaya and the Himalaya and their Implications on Gondwana and Cathaysia/Lauresia Continent Configurations," *Proceedings Third Regional Conference on Geology and Mineral Resources of Southeast Asia* (Bangkok: 1978), pp. 121-127.

Important evidence on the relationship of the Philippines with its neighbors during Mesozoic times is based on the results of palynological analysis of drill core obtained during the oil exploration of Northwest Palawan and Kalayaan bank. The fossils mentioned in the text were reported in unpublished biostratigraphic studies made on core from Penascosa, 1, Cadlao-1, Reed-Bank A-1 and B-1. These studies are among the data submitted to the Ministry of Energy by oil exploration companies. The palynology of Australia is reviewed in Basil E. Balme, "The Palynological Record of Australian Pre-Tertiary Floras," Lucy Cranwell (Ed.), *Ancient Pacific Floras* (Hawaii: 1964), pp. 49-80.

The complexity of Philippine basement geology and the fundamental questions relating to it are presented in Earl M. Irving, "Review of Philippine Basement Geology and its Problem," *Philippine Journal of Science*,

LXXIX: 3 (Sept. 1950), 267-307. The age of the oldest rocks in the basement that underlies the Philippines is a major problem. A carboniferous coral discovered by Mariano M. Melendres, Jr., and described in W. H. Easton and M. Melendres, Jr., "The First Paleozoic Fossil from Mindoro Philippine Archipelago," *UP Natural and Applied Science Bulletin,* XVIII: 3-4 (June, 1964), 229-232, places a minimum age of the Philippine basement as Carboniferous. Permian fossils in Mindoro and Panay are reported by Pacita P. Andal in "A Report on the Discovery of Fusulinids in the Philippines," *Philippine Geologist,* XX:1 (March, 1966), 14-22. Permian foraminifera from Mindoro are also reported by Toshio Koike, Wataru Hashimoto and Tadashi Sato, "Fusulinid-bearing Limestone Pebble Found ih the Agbahag Conglomerate, Mansalay, Oriental Mindoro, Philippines," *Geol. Paleont. Southeast Asia* IV (1968), 198-209. Conodonts are used to date Permian rocks in North Palawan as studied by Wataru Hashimoto and Tadashi Sato, "Geological Structure of North Palawan and Its Bearing on the Geological History of the Philippines," *Geol. Paleont. Southeast Asia,* XIII (1973), 145-161. Lower to Upper Permian algae from Mindoro are described by Riuji Endo, "Fossil Algae from Mindoro Oriental Province, the Philippines," *Geol. Paleont. Southeast Asia,* IV (1968), 211-219. Metamorphic rocks and folding in Mindoro are studied by Wataru Hashimoto and Tadashi Sato, "Contribution to the Geology of Mindoro and Neighboring Islands in the Philippines," *Geol. Paleont. Southeast Asia,* IV (1968), 192-210. Toshio Kimura, Akira Tokuyama, Benjamin A. Gonzales and Diosdado R. Andal study the structure of the Pre-Cretaceous basement in the Tayabas Isthmus in "Geologic Structures in the Tayabas Isthmus District, Philippines," *Geol. Paleont. Southeast Asia,* IV (1968), 156-178.

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Mineral Resources of Catanduanes Province (Manila: 1967); and Federico E. Miranda, "The Geology and Mineral Resources of Caramoan Peninsula, Camarines Sur, Philippines," *Jour. Geological Soc. Philippines*, XXX: NSDB Issue (1976), 18-54. Metamorphic rocks in the island of Rapu-Rapu adjacent to the Caramoan Peninsula form the country rocks of the copper deposits studied by Arthur R. Kinkel, Jr., and Sisenando Samaniego, *Geology of the Copper Deposits of the Hixbar Gold Mines, Inc., Rapu-Rapu Island, Albay* (Manila: 1956).

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Profound changes affected large regions of the globe during the Cretaceous. An account of the effect of these changes on Asian and European plants is reviewed by Michael Zohary, *Geobotanical Foundations of the Middle East:* Vol. 1 (Stuttgart: 1973). A description of the pollen during the Cretaceous to Eocene times in Sarawak is made by Jan Muller, "Palynology of the Pedawan and Plateau Sandstone Formations (Cretaceous-Eocene) in Sarawak, Malaysia," *Micropaleontology*, XIV:1 (1968), 1-37. Mangrove vegetation in Borneo, recorded as early as Paleogene times is also discussed by Jan Miller, "A Palynological Contribution to the History of Mangrove Vegetation in Borneo," In *Ancient Pacific Floras* Ed. Lucy Cranwell (Hawaii: 1964). An analysis of plant fossils is used by Jack A. Wolfe to interpret climatic changes during the Early Tertiary in "A Paleobotanical Interpretation of Tertiary Climates in the Northern Hemisphere," *American Scientist*, LXVI:6 (November-December 1978), 694-703. The effect of climatic changes in the Tertiary on vegetation, environment and human evolution is presented by Karl W. Butzar, "Environment, Culture, and Human Evolution," *American Scientist*, LXV:5 (Sept.-Oct. 1977), 572-584.

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A review of the Eocene in the Philippines is presented by Roberto R. Grey, "Eocene in the Philippines," *Philippine Geologist*, VIII:3, (Sept. 1954) 50-58. The environment of the Upper Eocene-Oligocene Aksitero formation is deduced by Francisco L. Amato, "Stratigraphic Paleontology in the Philippines," *Philippine Geologist*, XIX:1 (March 1965), 1-24. Eocene foraminifera in Micronesia are described by Shoshiro Hanzawa, *Cenozoic Foraminifera of Micronesia* (Richmond: 1957). Valuable information on the environment and history during Eocene times can be gathered from Victor de los Santos and J. Marvin Weller, *Geology and Coal Resources of the Hitoma-Manambrag Region, Catanduanes* (Manila: 1955); Oscar Crispin, J. Marvin Weller and Cesar Ibañez, *Geology and Coal Resources of the Panganiban Region, Catanduanes* (Manila, 1955); and, Victor C. de los Santos and Frank D. Spencer, *Geology and Coal Resources of Central Polilio Island, Quezon* (Manila: 1968). In the southwest, similarities in the geology and stratigraphy of the Cretaceous-Eocene in southwest Palawan and North Borneo are prescribed by Daniel M. Basco, "A Contribution to the Geology of Southwest Palawan Group of Islands (Balabac Island & Vicinity)," *Proceedings First National Symposium on Mineral Resources Development*, II:Sec. 9 (November 1964), 1141-1165.

Massive sulfide deposits associated with mid-Mesozoic to Early Paleocene faulting is discussed by Rolando A. de Guzman, "Geology and Remobilized Aspects of the Massive Sulfide Deposits of Port Bicobian, Ilagan, Isabela and Other Similar Philippine Deposits," *Philippine Geologist*, XXII:3 (September 1968), 109-132. The setting of Philippine chromite deposits is reviewed by George C. Bacuta, Jr., *Geology of Some Alpine-Type Chromite Deposits in the Philippines* (Manila: 1978). The biggest mineral deposit

of the Philippines and one of the biggest in the world is the Atlas copper deposit in Cebu found in Cretaceous to Paleogene rocks. The deposits are described by Luis Santos-Yñigo, "Copper Deposits of the Atlas Consolidated Mining and Development Corporation, Cebu," In *Copper Deposits of the Philippines* Ed. Arthur R. Kinkel, Jr. et.al. (Manila: 1956); and, Dominador Uy and Jose C. Vasquez, Jr., "The ACMDC Carmen Orebody; A Case History in Geochemical Exploration," *Jour. Geological Soc. Philippines*, XXVIII:4 (December 1974), 13-26.

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In addition to the work of Jan Muller previously mentioned, valuable information on the land plants of Southeast Asia during the Cenozoic can be obtained from Robert J. Morley, "Palynology of Tertiary and Quaternary Sediments in Southeast Asia." *Proceedings Indonesian Petroleum Association 6th Annual Convention* (May 1977), 255-276. The diversity of land plants in the Philippines can be deduced also from the unpublished reports on the biostratigraphy of oil wells drilled in Palawan and the Sulu Sea. During Neogene times, the diversity of marine life in the Philippines are reflected in the various species reported in the review of Philippine paleontology by Dickerson and Hashimoto already mentioned and also in the classic paper by Roy E. Dickerson, "A Fauna of the Vigo Group; Its Bearing on the Evolution of Marine Molluscan Faunas," *Philippine Journal of Science*, XVIII:1 (January 1921), 1-21, where differences between the rates of survival of molluscs in the tropics and temperate regions are noted. The use of molluscs to calculate Lyellian percentages can also be found in the paper by Tsugio Shuto, "Neogene Gastropods from Panay Island, the Philippines," *Geol. and Paleont. Southeast* Asia, VI (1969), 1-250. The fossils are also used to infer the past environments. Molluscs of the Iloilo Basin are also described by Remedios Samaniego, Reynaldo E. Yago and Manuel G. Flores, "Fossil Molluscs from the Iloilo Basin," *Jour. Geol. Soc. Philippines*, XXIV:2 (June 1970), 68-119.

The richness of marine life and environments in the Philippines during the Neogene is also documented by Albert V. Carozzi, Milagros V. Reyes and Victoriano P. Ocampo, *Microfacies and Microfossils of the Miocene Reef Carbonates of the Philippines* (Makati: 1976). The use of foraminifera to determine age and paleogeology of Neogene sediments is demonstrated by Ernesto A. Espiritu, Elvira P. Ordoñez and Manuel G. Flores, "Biostratigraphy of Bondoc Peninsula, Quezon," *Philippine Geologist*, XXII:2 (June, 1968), 63-90; Paz D. Santiago, Faunal Successions in Eastern Luzon Central Valley (Manila: 1970). Along this line of approach in the study of past environments, a standard reference is the paper of Orville L. Bandy, "Cenozoic Planktonic Foraminiferal Zonation and Basinal Development for the Philippines," *Philippine Geologist*, XVI:3 (September 1962), 12-34. Orville L. Bandy also contributed to the fixing of age boundaries in "Miocene-Pliocene Boundary in the Philippines as Related to Late Tertiary Stratigraphy of Deep-Sea Sediments," Science, CXLII:3597 (1963), 1290-1292. Also contributing to the data on the Neogene foraminifera are the papers of Benjamin A. Gonzales, *Foraminiferal Analyses on Measured*

Section along the Tarao (Jarao) and Tanjan Rivers (Manila: (1963); and, Hiroshi Ujie and Tetsumo Samato, "Pliocene-Upper Miocene Planktonic Foraminiferal Faunas from Northern Mindanao, Philippines," *Geol. and Paleon, Southeast Asia.* The geology, paleontology and paleoenvironment of the eastern part of Central Luzon which is underlain by a thick sequence of Neogene rocks is presented in Benjamin A. Gonzales, Victoriano P. Ocampo and Ernesto A. Espiritu, "Geology of Southeastern Nueva Ecija and Eastern Bulacan Provinces, Luzon Central Valley," *Jour. Geol. Soc. Philippines*, XXV:2 (June 1971), 1-41.

A wealth of information is being disclosed by-ongoing petroleum exploration in the Philippines. In the Central Luzon Basin, an interpretation of the evolution of the basin through time in the basin analysis by P. R. Baumann, M. E. Latrelle, P. Maurizot, *The Hydrocarbon Potential of the Central Luzon Basin, Philippines* (3 Vol.), (Manila: 1977). Information on the Sulu Sea and other areas subjected to petroleum exploration may be gleaned from Dominador Muriel, "Summary of Petroleum Exploration in the Philippines, 1972-1974," *Jour. Geol. Soc. Philippines*, XXVIII:4 (Dec. 1974), 27-34. The geology, representative sections and geological history of the Northwestern Palawan offshore areas is presented by Emmanuel V. Tamesis, Edward V. Mañalac, Carlos A. Reyes and Leonardo M. Ote, "Late Tertiary Geologic History of the Continental Shelf of Northwestern Palawan, Philippines," *Geol. Soc. Malaysia Bulletin*, 6 (July 1973), 165-176. Data on the Nido oil field in Palawan can be obtained from a recent paper by Allen G. Hatley, "The Philippines Nido Reef Complex Oil Field: A Case History of Exploration and Development of a Small Oil Field," *Offshore Southeast Asia Conference* 26-29 February 1980, SEAPEX Session, Singapore. A review of exploration in various sedimentary basins in the Philippines is given by Arthur Saldivar-Sali, *Reef Exploration in the Philippines* (Makati: 1978). A regional synthesis on oil plays in Southeast Asia prepared by the Exploration Staff of Cities Service Company was presented by Leslie Beddoes, Jr., "Hydrocarbon Plays in Tertiary Basins of Southeast Asia," *Offshore South East Asia Conference*, SEAPEX Session, 26-29 February 1980, Singapore.

Descriptions of coal deposits are also excellent sources of information on the geology, stratigraphy, and sometimes the paleontology and geological history of Neogene sedimentary areas in the Philippines. The standard source of data on coal was published in the coal project series of the Philippine Bureau of Mines (now the Bureau of Mines and Geosciences) in the mid-50's. A summary of the coal resources of the Philippines was made by Frank D. Spencer and Jose F. Vergara, *Coal Resources of the Philippines* (Manila: 1957), Publication No. 20 of the Bureau of Mines Special Projects Series. The other titles belonging to the coal series are as follows: J. Marvin Weller and Jose F. Vergara, *Geology and Coal Resources of the Bulalacao Region, Mindoro Oriental* (Manila: 1955), No. 1; Oscar Crispin, Marvin Weller, and Cesar B. Ibañez, *Geology and Coal Resources of the Panganiban Region, Catanduanes* (Manila: 1955), No. 2; Oscar Crispin, J. Marvin Weller, and Jose F. Vergara, *Geology and Coal Resources of Bataan Island, Albay* (Manila: 1955), No. 3; Victor de los Santos and J. Marvin

Weller, *Geology and Coal Resources of the Hitoma-Manambrag Region, Catanduanes* (Manila: 1966), No. 4; Cesar B. Ibañez, Harley Barnes, and Juan de la Cruz, *Geology and Coal Resources of the Gatbo Peninsula Bacon-Prieto Diaz-Gubat Region, Sorsogon* (Manila: 1955), No. 5; Jose F. Vergara, *Geology and Coal Resources of Semirara Island, Antique* (Manila: 1955), No. 6; Harley Barnes, Cresencio P. Jongco, Generoso C. Lazaga, Juan E. Pilac, and Harold E. Vokes, *Geology and Coal Resources of the Argao-Dalaguete Region*, Cebu (Manila: 1956), No. 7 Cesar B. Ibañez, Ignacio S. Antonio, Harley Barnes, and Luis Santos-Yñigo, *Geology and Coal Resources of the Malangas Kabasalan Region, Zamboanga del Sur* (Manila: 1956), No. 8; Mariano M. Melendres, Jr. and Harley Barnes, *Geology and Coal Resources of the Calatrava-Toboso Region, Occidental Negros* (Manila: 1957), No. 12; Jose F. Vergara and Frank D. Spencer, *Geology and Coal Resources of the Bislig-Lingig Region, Surigao* (Manila: 1957), No. 14; Victor C. de los Santos and Frank D. Spencer, *Geology and Coal Resources of Central Polilio Island, Quezon* (Manila: 1968), No. 15. The data on coal was updated recently by a study commissioned by the Ministry of Energy and conducted by the Robertson Research, Inc. of Singapore.

Asphalt and hydrocarbon occurrences in Leyte are studied by Demetrio N. Palacio, "Preliminary Report on the Geology and Rock Asphalt Deposits of Balite, Villaba, Leyte," *Philippine Geologist*, XI:3 (June 1957), 69-100; and, Raymundo A. Reyes, Jr., "Hydrocarbon Distributions and Carbon Isotope Variations in the Surface Petroleum Occurrences and Potential Source Rocks in Northwest Leyte," *Jour. Geol. Soc. Philippines*, XXXIII:1 (March 1979), 1-33. The geology and structure of Miocene sandstones in Southern Palawan are found in Manuel M. Gamboa, "The Massive Arenaceous Sandstone in Tagbita, Southern Palawan—A Potential Source of Flintgrade Glass Sands," *Jour. Geol. Soc. Philippines*, XXIX:2 (June 1975), 6-18.

A description of the alkalic igneous rocks in Isabela can be found in Jaime R. Palispis, "Geology and Geochemistry of the Oligo-Miocene Magat Volcanics in the Magat Damsite, Ramon, Isabela," *M. S. Thesis*, University of the Philippines (March 1977); and, Ulrich Knittel, "Petrography and Origin of the Syenite from Cordon, Isabela," *Jour. Geol. Soc. Philippines*, XXXXIII: 1 (March 1979), 34-43. A detailed study of one of the minerals from Cordon is made by Raymundo A. Reyes, Jr., "Pseudoleucites of Cordon, Isabela," *Jour. Geol. Soc. Philippines*, XXXI:1 (March 1971), 38-56. Trends in the evolution of Miocene intrusives can be found in John Wolfe, M. S. Manuzon and A. F. Davis, "The Taysan Porphyry Copper Deposit, Southern Luzon Island, Philippines," *Economic Geology*, LXIII: (March 1978), 608-617. An age of a Miocene intrusive in Batangas and strontium isotope ratios in two igneous rocks from Taysan are given in their paper. The geology of another intrusive in Marinduque containing copper deposits is described by A. G. Loudon, "Marcopper Porphyry Copper Deposit, Philippines," *Economic Geology*, LXXI:4 (June-July 1976), 721-732.

Contact metasomatic deposits formed during the Neogene intrusions of igneous rocks are described in John E. Frost, "Notes on the Genesis of the Ore-bearing Structures of the Paracale District, Camarines Norte,

Philippines, *Philippine Geologist*, XIII:2 (June 1950), 31-34; Juanito C. Fernandez, "Geology of the Lammin Iron Deposits, Piddig, Ilocos Norte," *Philippine Geologist*, XVIII:1 (March 1964), 10-19; and Eleno C. Yray, "Notes on the Geology of the Iron Mine of Sta. Ines Steel Corporation at Sta. Ines, Antipolo, Rizal," *Mining Newsletter*, XVI:1 (Sept.-Oct. 1964), 9-20. The copper deposits in Lepanto are described by Fred E. Johnson, Ottey M. Bishop and William G. Peryam, "Mining and Reduction of Enargite Ores at Lepanto, Mankayan, Philippine Islands," *Mining Technology*, VI:3 (May 1942), Technical Publication 1452; and, Arsenio Gonzalez, "Geology of the Lepanto Copper Mine, Mankayan, Mountain Province," In *Copper Deposits of the Philippines*, Ed. Arthur Kinkel *et. al.* (Manila: 1956). Modern techniques in the study of the genesis of gold deposits in Benguet are made by F. J. Sawkins, J. R. O'Neil and J. M. Thompson, "Fluid Inclusion and Geochemical Studies of Vein Gold Deposits, Baguio District, Philippines," *Economic Geology*, LXXIV:6 (Sept.-Oct. 1979), 1420-1434.

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The Quaternary is a term originally applied by Jules Pierre Stanislas Desnoyers in "Observations sur un ensemble de depots marins plus recent que les terrains tertiaires du bassin de la seine, et constituant une formation geologique distincte; precedees d'un apercu de la non-simultaneite des bassin tertiare," *Annales des Science Natureles* (Paris: 1829) v. 16, p. 171-214, 402-491 to deposits overlying Tertiary rocks in the Paris basin. It was defined by H. Reboul as deposits with fauna and flora still living in *Geologie de la Periode Quaternaire* (Paris 833). Soon afterwards, Charles *Lyell* introduced the term Plestocene, meaning most recent, for deposits with more than 70% molluscs represented by living species in *Noveaix Elements de Geologie* (Paris: 1839). The term Holocene, meaning wholly recent, was established in the 1885 International Geological Congress.

The beginning of the Holocene is placed at 10,000 radiocarbon years ago as recommended by the Holocene Commission of the International Union for Quaternary Research (INQUA). The definition of the beginning of the Quaternary, on the other hand, is not yet clearly settled. The 1948 International Geological Congress recommended that it be defined at the base of the marine Calabrian Stage with the type locality at Santa Maria di Catanzaro, Calabria, Italy. The current trend, as in the estimate of B. U. Haq, W. A. Berggrea and J. A. van Convering, "Corrected Age of the Pliocene Boundary," *Nature* CCLXIX: (1877) 483-488, is to place the beginning of the Quaternary, and also the Pleistocene, at a time slightly younger than the Olduvai event during which there was a reversal of north and south poles, about 1.61 million years ago. The Pliocene-Pleistocene boundary in Pacific sediments is discussed by T. Saito, "The Pliocene-Pleistocene Boundary in Pacific Deep-Sea Sediment Cores," *Abstracts First International Congress on Pacific Neogene Stratigraphy* (Tokyo, 1976), 178-179. For a detailed discussion of issues relating to the Quaternary Period, reference may be made to David Q. Bowen, *Quaternary Geology—A Stratigraphic Framework for Multi-disciplinary Work* (London: 1978).

Climatic change which dominates the Quaternary had a widespread influence on environment and human evolution. One result of fluctuations in climate is the advance and retreat of glaciers. The origin of glaciation is explained by Chester B. Beaty, "The Causes of Glaciation," *American Scientist* LXVI:4 (July-August 1978), 452-459. Traditional models of ice sheet growth are reviewed by R. F. Flint, *Glacial and Quaternary Geology* (New York: 1971). Glacial effects observed in Borneo are listed in John R. Flenley and Robert J. Morley, "A Minimum Age for the Deglaciation of Mt. Kinabalu, East Malaysia," *Modern Quaternary Research S. E. Asia* IV (1978), 57-61. These are also noted in Taiwan by C. C. Lin, "Geology and Ecology of Taiwan Prehistory," *Asian Perspectives*, VII:1-2 (Summer Winter 1963), 203-213. C. C. Lin also review the Pleistocene stratigraphy, fauna and land bridges between Taiwan and Northern Luzon. The fluctuations in climate during the Quaternary are also detected in ocean sediments and the fluctuations in the Pacific are studied by Mark J. Valencia, "Pleistocene Stratigraphy of the Western Equatorial Pacific," *Geol. Soc. America Bull.*, XXCVIII:1 (Jan. 1977), 143-150; and, "Pacific Pleistocene Paleoclimatic Stratigraphies: A Comparative Analysis of Results," *Quaternary Research* VIII (1977), 339-354.

The withdrawal of water from the sea during periods of glaciation results in a lowering of the sea level. Patterns of sea level changes during the last 100,000 years are inferred by J. M. A. Chappel, "Geology of Coral Terraces, Huon Peninsula, New Guinea: A Study of Quaternary Tectonic Movements and Sea Level Changes," *Bull. Geol. Soc. America*, LXXXV: (Sept. 1974), 553-570. Sea level changes during the late Quaternary are estimated by F. P. Shepard, "Thirty-five Thousand Years of Sea Level," In *Essays in Marine Geology in Honor of K. O. Emery* (U. of Southern California Press: 1963), 1-10, and by N. A. Morner, "Late Quaternary Isostatic, Eustatic and Climate Changes," *Quaternaria*, XIV:1 (Sept. 1971), 63-83. The combination of fluctuating sea level and uplift give rise to raised marine terraces. The patterns of marine terraces in the Western Coast of India are studied by K. K. Verma and U. B. Mathur, "High Stands of Quaternary Sea along the Western Coast of India—a New Area for the Test of Glacioeustasy in Asia," *Proceedings III GEOSEA* (Bangkok: 1978), 113-118. The age of terraces in Taiwan are determined and used to estimate uplift rates in Tsung-Hung Peng, Yuan-Hui Li and Francis T. Wu, "Tectonic Uplift Rates of the Taiwan Island Since the Early Holocene," *Memoir Geol. Soc. China No. 2* (October 1977), 57-69. In the Philippines, effects of sea level changes and uplift during the Quaternary are studied by George D. Louderback, "Post-Pliocene Diastrophism in Cebu, P. I.," *Proceedings Fourth Pacific Science Congress* (Java: 1930), v. II, 775-780 and by Jose M. Feliciano and Vinicio R. Pelaez, "Pleistocene Orogenic Movements in the Philippines," *Proceedings Sixth Pacific Science Congress* (Berkeley: 1940) v. II, 811-814. The development of the Philippine strand line is described by Leopoldo A. Faustino, "History of the Strand Line of the Philippine Islands during Pleistocene and Post-Pleistocene Time," *Proceedings Third Pacific Science Congress* (Tokyo: 1926), 1807-1811. Philippine coastal features and Pleistocene paleogeography are discussed by Roy E.

Dickerson, "Tertiary Paleogeography fo the Philippines," *Philippine Journal of Science* XXV:1 (July 1924), 11-50. In this paper, Dickerson quotes a letter from Graham B. Moody who suggests that Mindanao was divided into five major islands during Early or Middle Pleistocene times. Uplift of Mindanao is also discussed by Antonio D. Alvir, "The Island of Mindanao, Philippines: A Uplifted Peneplain," *Proceedings Eighth Pacific Science Congress* (Quezon City: 1956), 278-280. Sea level fluctuations contributed to the development of the double barrier reef of Bohol described by M. Pichon, "Physiography, Morphology and Ecology of the Double Barrier Reef of North Bohol (Philippines)," *Proceedings Third International Coral Reef Symposium* (Miami: 1977).

Sea level changes and uplift gave rise to land connections between the Philippines and its neighbors. The pattern of these connections during the Quaternary and pre-Quaternary times are inferred in the works of Roy Dickerson already cited ("Tertiary Paleogeography of the Philippines", 1924; and, *Distribution fo Life in the Philippines*, 1928). Patterns in the distribution of land plants given by Robert J. Morley, "Palynology of Tertiary and Quaternary Sediments in Southeast Asia," *Proceedings Indonesian Petroleum Association 6th Annual Convention* (May 1977), 255-276, illustrate the influence of climate and sea level changes in the distribution of plants in Southeast Asia. Various evidences for land connections between the Philippines and Southeast Asia are reviewed by Benjamin Austria, "Land Bridges", *Filipino Heritage* (Singapore: 1977) v. I, 7-13.

Land bridges permitted the migration of large vertebrates, including man, to the Philippines. Thus, an extinct elephant, Stegodon, is found in various parts of the Philippines and an early description of this elephant is given by Edmund Naumann, "*Stegodon mindanensis*, eine Art von Uebergangs-Mastodonten," *Zeitschrift der deutschen geologischen Gesellschaft*, XLII:1 (1980), 166-169. Descriptions of fossil vertebrates in the Philippines are also given by G.H.R. von Koenigswald, "Fossil Mammals from the Philippines," *Proceedings Fourth Far Eastern pre-History Congress* Manila: 1956), Paper 22, 23 p.; H. Otley Beyer, "New Finds of Fossil Mammals from Pleistocene Strata of the Philippines," *National Research Council of the Philippines Bull.*, VLI (Feb. 1957), 220-229; and, Silvio M. Lopez, "Notes on the Occurrence of Fossil Elephants and Stegodonts in Solana, Cagayan, Northern Luzon, Philippines," *Jour. Geol. Soc. Philippines*, XXV:4 (December 1971), 1-8. An enumeration of animal remains found in Cagayan is given by Mark E. Mathisen and Carl F. Vondra, "Pleistocene Geology, Fauna and Early Man in the Cagayan Valley, Northern Luzon, Philippines," *Abstracts with Programs*, 1978 Joint Annual Meeting, GSA-GAC-MAC (Toronto: 1978), 451.

In some areas of the Philippines, dark glassy rocks known as tektites are associated with Pleistocene deposits containing artifacts. Tektite papers of H. Otley Beyer are collected in *Philippine Tektites* (Quezon City: 1960). Hypotheses on the origin of tektites are reviewed in John A. O'Keefe, "The Tektite Problem," *Scientific American*, CCXXXIX:2 (August 1978), 98-107. The age of tektites in Southeast Asia and Australia are studied

in G.H.R. von Koenigswald, "Tektite Studies I: The Age of the Indo-Australian Tektites; II: The Distribution of the Indo-Australian Tektites," *Proc. Kon. Ned. Akad. Wetesch.*, LXIII:Series B (1960), 135-153; and, R.O. Chalmers, E.P. Henderson and Brian Mason, "Occurrence, Distribution, and Age of Australian Tektites." *Smithsonian Contribution to the Earth Sciences*, No. 17, 46 p.

The active volcanoes of the Philippines are catalogued in M. Neumann van Padang, *Catalogue of the Active Volcanoes of the World: Part II. Philippine Islands and Cochin China* (Naples: 1953). A description of the catastrophic 1965 eruption of Taal Volcano is presented in James G. Moore, Kazuaki Nakamura and Arturo Alcaraz, "The 1965 Eruption of Taal Volcano," *Science*, CLI:3713 (February 25, 1966), 955-960. The history of Quaternary volcanism in the Bataan Peninsula is documented in the Project Study for the Philippine Nuclear Power Plant. Quaternary volcanism offers a vast source of geothermal energy. The field around Tongonan is described by D.B. Abiog, "Geothermal Study of Tongonan Springs. Ormoc City, Leyte," *Journal Geol. Soc. Philippines* XIII:2 (June 1969), 78-97. The exploration of the Tongonan field is described by Nazario C. Vasquez, "A Case History: The Tongonan Geothermal Field," *Program and Abstracts First Symposium on Geo-Energy Resources of the Philippines* (Makati: 1979), p. 28. In the same symposium, Alfredo C. Troncales presents the "Regional Setting of Philippine Geothermal Areas," *Programs and Abstracts*, p. 27.

In addition to geothermal energy, mineral resources are also found in Quaternary rocks of the Philippines. The mercury deposits of Palawan are described by Henry E. Fernandez, "The Geology of Cinnabar Deposits of Central Palawan," *Philippine Geologist* XXII:2 (June 1968), 91-105. Philippine laterites, now mined as a source of nickel, are discussed in Luis Santos-Yñigo, "Chemical Evolution and Variations in Philippine Laterites," *Philippine Geologist*, XXI:2 (June 1967), 13-14; and in Luis Santos-Yñigo and Fernando B. Esguerra, *Geology and Geochemistry of the Nickeliferous Laterites of Nonoc and Adjacent Islands, Surigao Province* (Manila: 1961). Bauxite, which is the source of aluminum, are studied by Ruperto B. Jagolino, "Bauxite Deposits of Samar," *Jour. Geol. Soc. Philippines*, XXX (NSDB Issue; 1976), 1-19.

APPENDIX

Partial list of species from the Vigo group

Architectonica pictum (Philippi).
Actaeon reticulatus K. Martin.
Buccinium simplex K. Martin.
Bullaria ampulla (Linnaeus).
Cancellaria crenifera Sowerby.
Cancellaria elegans Sowerby.
Cassidaria.
Cerithium jenkinsi K. Martin.
Cerithium herklotsi K. Martin.
Cerithium moniliferum Kieper.
Cerithium bandongensis K. Martin.
Cerithium sp. nov.
Cerithium jonkeri K. Martin.
Cerithidea cf. ornata Hinds.
Cerithidea (Pyrazus) cf. sulcatus Bruguiere.
Cerithidea cf. quadrata Sowerby.
Conus ornatissimus K. Martin.
Conus sp. nov.?
Conus sp.
Conus lividus Hwass.
Conus loroisii Kienei.
Conus hardi K. Martin.
Conus striatellus Jenkins.
Columbella bandongensis K. Martin.
Cyclonassa elegans Kiener.
Cypraea ef. tigris Linnaeus.
Cypraea sp.
Drillia sp.
Delphinula?
Delphinula reeviana Hinds.
Distortio clathrata Lamarck.
Eburna ambulacrum Sowerby.
Ficus reticulata (Lamarck).
Haminea.
Harpa articularis Lamarck.
Mitra javana K. Martin.
Mitra cf. jenkinsi K. Martin.
Mitra junghuhni K. Martin.
Mitra bucciniformis K. Martin.
Mangelia.
Murex endivia Lamarck.
Marginella.
Melania aspereta Linnaeus.

Melania aspereta inquinata Quadras.
Nassa crenulata (Bruguiere).
Nassa dispar Adams.
Nassa gemmulata (Lamarck).
Nassa globosa minor Quoy.
Nassa thersites immersa Carpenter.
Nassa thersites leptospira (Bruguiere).
Nassa quadrasi Hidalgo
Nassa canaliculata Lamarck.
Nassa costellifera A. Adams.
Nassa reussi K. Martin (*may = N. costellifera*).
Natica albumen Lamarck.
Natica?
Natica spadicea Reeve.
Natica mamilla Lamarck.
Natica lacernula d'Orbigny.
Natica cumingiana Recluz.
Nerita funiculata Reeve.
Olivella.
Phos roseatus Hinds.
Ranella.
Ranella subgranosa Beck.
Ranella tuberculata Broderip.
Ricinula spectrum Reeve.
Rostellaria fusus Linnaeus.
Rostellaria crispata Kiener.
Strombus canarium (Linnaeus).
Strombus, sp. a.
Strombus, sp. b.
Strombus swainsoni Reeve.
Strombus (*?*) *fusus* K. Martin.
Strombus (*?*) *sp.*
Turris (*Surcula*) *flavidula* Lamarck.
Turris garnonsi Reeve.
Turris deshayesi (Doumet).
Turris carinata woodwardi K. Martin.
Turris coronifer (K. Martin).
Turris marmorata (Lamarck).
Terebra bicineta K. Martin.
Terebra javana K. Martin.
Terebra.
Triton pfeifferianum Reeve.
Trochus.
Telescopium telescopium Linnaeus.
Trivia smithi K. Martin
Voluta cf. innexa Reeve.

PELECYPODA

Arca cornea Reeve.
Arca ferruginea Reeve.
Arca granosa Linnaeus.
Arca cf. coelata Reeve.
Arca tenebrica Reeve.
Barbatia fusca (Bruguiere).
Cardium.
Cardium attenuatum Sowerby.
Cardium donaciformis Cuming.
Cardium unicolor Sowerby.
Cardita antiquata Linnaeus.
Chione chlorotica Philippi.
Chione?
Corbula scaphoides Hinds.
Corbula socialis K. Martin.
Clementia hyalina Philippi = *C. papyracea.*
Dosinia cf. lenticularis.
Dosinia cretacea Philippi.
Glycimeris viteus (Lamarck).
Glycimeris angulatus (Lamarck).
Ostrea.
Paphia textrix Deshayes.
Pecten (Pleuronectia) pleuronecta Linnaeus.
Pecten cf. radula Linnaeus.
Pecten cf. pseudolima Sowerby.
Pecten pseudolima Sowerby.
Pecten cf. cristularis Adams and Reeve.
Placuna placenta Linnaeus.
Psammobia cf. lessoni Blainville.
Psammobia sp.
Pinna sp.
Solen sp.
Spisula sp.
Solecurtus quoyi Deshayes.
Spondylus sp.
Tellina sp.
Vermetus javanus? K. Martin
Vermetus sp. nov.

GLOSSARY

AMMONITES—Any of numerous fossil shells of cephalopods having the form of a sharp spiral similar to that of the nautilus and especially abundant in the Mesozoic age, some being 3 feet or more in diameter

ANTICLINES—an upfold or arch of stratified rock in which the beds or layers dip in opposite directions from the crest

AQUIFERS—a stratum of permeable rock, sand, etc., which contains water, especially one which acts as a water source for a well or the like

ARCHAEOLOGY—the science of antiquities, especially prehistoric antiquities, which investigates the history of peoples by the remains belonging to the earlier period of their existence

ARCHAEZOIC—of, belonging to, or relating to the earliest era of geological history, the era of the archean rocks

ASTHENOSPHERE—a hypothetical earth-circling shell or zone which lies from 30 to 75 miles below the earth's surface and within which the material not necessarily molten is believed to yield more rapidly to persistent stresses than the rigid crust above or the solid nucleus below

ATOLL—a coral island, consisting of a strip or ring of coral surrounding a central lagoon or lake

BARRIER REEF—a coral reef rising from a great depth to the level of low tide, encircling an island like a barrier, or running parallel to a coast, with a navigable channel inside

BASALT—a dark gray to black, dense to fine grained igneous rock that is the extrusive equivalent of gabbro

BATHOLITHIC—a great mass of intruded igneous rock that for the most part stopped in its rise a considerable distance below the surface and that extends downward to unknown depth

BAUXITE—an aluminum ore derived from various rocks preferably deficient in silica and iron

BENTONITE—a rock consisting mainly of the clay minerals montmorillonite and beidellite, formed from the decomposition of volcanic ash, capable of absorbing large quantities of water, and capable of being activated by acid: used as an emulsifier and drugs and as a carrier for chemicals

BIOHERM—a body of rock built up by or composed mainly of sedimentary organisms (as corals, algae, or mollusk) and enclosed or surrounded by rock of different origin

BRECCIA—an aggregate composed of angular fragments of the same rock or of different rocks united by a matrix or cement

BRYOZOA—a small phylum of aquatic animal, that reproduce by budding, that usually form branching, flat, or mosslike colonies permanently attached on stones or seaweeds and enclosed by an external cuticle soft and gelatinous or rigid and chitinous or calcareous, and that consist of complex zooids each having an alimentary canal with distinct mouth and anus surrounded by a true coelom and associated with a protrusible lophophere

CAMBRIAN—earliest division of the Paleozoic era and the lowest system of Paleozoic rocks next below the Ordovician and above the Kerveenawan

CARBONIFEROUS—pertaining to the stage of the Paleozoic period following the Devonian or to the coal bearing rocks formed during that age

CENOZOIC—of or relating to a grand division of geological history including the entire interval from the beginning of the Tertiary period to the present time marked by a rapid evolution of mammals and birds and of grasses, shrubs and higher flowering plants and by little change in the invertebrates

CHEVROTAIN—any of several very small hornless deerlike ruminant mammals of tropical Asia, the Malay archipelago, and West Africa superficially resembling the musk deer, the male having short tusks, and being among the smallest known ruminants standing only about a foot high

CHONDRITE—a meteoric stone characterized by the presence of chondrules

CHONDRULES—a rounded granule of cosmic origin usually consisting of enstatite or chrysolite and occurring embedded more or less abundantly in the mass of many meteoric stones and sometimes free in marine sediments

CIRQUE—a deep steep-walled basin high on a mountain usually shaped like half a bowl and often containing a small lake caused especially by glacial erosion, and nonforming the blunt head of a valley

CONODONT FAUNA—any of certain minute toothlike fossils found in Paleozoic rocks

CONVECTION CURRENT—the motion of electrically charged particles, or of a charge when carried on a piece of conductor dielectric

CORAL REEF—an extensive reef built by the gradual deposit of coral and other organic matter, part of which has become limestone

COSMOGONY—a part of the science of astronomy that deals with the origin and development of the universe and its components

CRETACEOUS—of or relating to the last period of the Mesozoic era and the corresponding system of rocks, the deposits of the period including the larger part of the known chalk beds, greensand mark, and

most of the coal of the U.S. west of the Great Plains, the vegetation of the period having approached the modern temperate and subtropical flora in general aspect, and the reptiles of the period having remained dominant on the land and in the sea, ganoid fishes for the first time having become subordinate to teleosts

DACITE—a light colored volcanic rock containing quartz

DACITIC PYROCLASTICS—rock consisting of dacite fragments formed by explosive volcanism

DELTA—a triangular tract of alluvial land between diverging branches of the mouth of a river, often intersected by other branches

DEVONIAN—period of the Paleozoic which follows the Silurian and is next below the Mississippian and the system of rocks formed during the period

DIASTROPHISM—the process of deformation that produces in the earth's crust its continents and ocean basins, plateaus and mountains, folds of strata, and faults

DIORITE—a coarse-grained plutonic intermediate igneous rock, consisting essentially of intermediate plagioclase

DIPTEROCARPACEAE—a family of trees chiefly of tropical Asia yielding valuable wood and aromatic oils and resins and distinguished by having 2-winged fruit

DRYOPITHECUS—on genus of generalized miocene and pliocene old world apes sometimes regarded as common ancestral forms of the anthropoid ages and man

ECHINODERM(S)—pertaining to the phylum of marine animals consisting of the starfishes, sea urchins and their allies

EOCENE—of or relating to the second principal subdivision of the Tertiary —used commonly of the epoch following the Paleocene and preceding the Oligocene but sometimes of all the Cenozoic era preceding the Miocene

EROSIONAL PROCESS—the general process of the wearing away of rocks at the earth surface by natural agencies

ESKERS—a long narrow often sinuous ridge or mound of sand, gravel, and boulders deposited between ice walls by a stream flowing on, within, or beneath a stagnant glacier

FAULTS—a fracture in the earth's crust accompanied by a displacement of one side of the fracture with respect to the other and in a direction parallel to the fracture

FELDSPAR—any of a group of usually white or nearly white, flesh-red, bluish, or greenish minerals that are closely related in crystalline

form, that are all aluminum silicates with potassium, sodium, calcium, or barium, that occur in crystals and crystalline masses

FISSION—the process or an instance of cleaving, splitting or breaking up into parts

FLUVIATILE—belonging to, existing in or about, or produced by the action of streams or rivers

FLYSCH—sedimentary and igenous rocks deposited during the early stages of geosynclinal evolution

FORAMINIFERA—an order of Rhizopoda comprising of large and chiefly marine protozoans that have one or more nuclei that are generally enclosed in a typically calcerous shell having minute opening for slender branching pseudopodia and consisting of several successively formed communicating chambers each larger than the preceding, that have a complex life cycle in which sexual and asexual generations alternate, that are so abundant that their shelly remains constitute a major part of various sedimentary limestone and serve to identify geological horizons

FOSSIL—any remains, impression or trace of an animal or plant of past geological ages that has been preserved in the earth crust

FUSULINIDS—a genus of spindle-shaped, perforate Foraminifera abundant in the Carboniferous

GABBRO—a rock of a family of granular igneous rocks composed essentially of calcie plagioclase, a ferromagnesian mineral and accessory minerals

GEOSYNCLINE—a great downward flexure of the earth's crust

GEOTHERMAL ENERGY—consist of heat flowing from the earth's interior

GLACIATION—the conversion into ice as in the scoring or erosion of rocks

GLAUCOPHANE—a blue mineral formed at high pressures and relatively low temperatures

GRANODIORITE—a granular intrusive quartzose igneous rock intermemediate between granite and quartz disrite with plegioclase predominant over orthoclase

GRAPTOLITE(S)—any of numerous fossils of a group Graptolitoidea found from the upper Cambrian through the Devonian and generally regarded as constituting a subclass of Hydrozoa

GRAYWACKE—an impure sandstone common in the Lower Tertiary and its occurrence indicates a source area of high relief that is being eroded rapidly thus giving rise to the mixture of sand, silt and clay

GYMNOSPERM—a plant of the class gymnospermae; or a plant having seeds not enclosed in any ovary or carpel

HORNBLENDE DIORITE—amphibole, properly the common dark aluminous variety

ICE AGE—the Pleistocene glacial epoch, a period during which extensive glaciation occurred

IGNEOUS ROCK—rock formed by solidification of a molten magma

ISOTOPES—one of two or more species of the same element, having the same atomic number and hence occupying the same position in the periodic table and nearly identical in chemical behavior but differing in atomic masses

ISTHMUS—a narrow strip of land running through a body of water and having the water lying at each side and connecting two larger land areas

JURASSIC—constituting or relating to the period of the Mesozoic era preceding the Comanchean and succeeding the Triassic and the cor-

MONZONITE—a granular igneous rock

LACUSTRINE—of or relating to dwellings buit on piles in lakes especially in prehistoric central Europe, Scotland, and Ireland

LIMESTONE—a rock consisting of carbonates like those that compose the framework of coral reefs

LITHOSPHERE—the solid part of the earth; specifically the outer part of the solid earth composed of rock essentially like that explored at the surface and believed to be about 50 miles in thickness

MAGMA—melting of some of the rocks to again give rise to the silicate melt

MARINE TERRACE—a terrace formed along a seashore by the merging of wave-cut and wave-built terraces

MARSUPIAL(S)—an order of mammals including the kangaroos, handicoats, and opossums of which the female has a pouch or pocket in the abdomen in which to carry the young

MELANGE—mixture of different rocks

MERITIC ENVIRONMENT—a region of shallow water adjoining the seacoast and usually considered to extend from low-tide mark to a depth of 100 fathoms

MESOZOIC—of or relating to a grand division of geological history that includes the entire interval of time between the Permian and the Tertiary and is marked by the dinosaurs, marine and flying reptiles, ganoid fishes, cycads, and evergreen trees

METALLURGY—a science and technology that deals with the extraction of metals from their ores, refining them and preparing them for use and includes processes

METAMORPHISM—any change in the composition of any kind of rock, generally effected by action of pressure, heat, and water resulting in a more compact and more highly crystalline condition of the rock

METAMORPHOSIS—charge of form, structure or substance

METAZOA—a group that comprises all animals having the body when adult composed of numerous cells differentiated into tissues and organs and usually to include the Coelenterata and all higher animals but sometimes is extended to include the Parazoa and Mesozoa

METEORITE—solid particle from interplanetary space that survives the destructive effects of a flight through the earth's atmosphere and falls to the ground in one or more pieces

MIACIDS—a family of primitive generalized carnivorous mammals widely distributed from the Paleocene through the lower Oligocene

MIOCENE—of, relating to, or characterizing an epoch of the Tertiary preceding the Pliocene and succeeding the Oligocene

MOHOLE PROJECT—a deep drill hole which would pierce the Mohorovicie discontinuity and reach the upper mantle

MONZONITE—a granular igneous rock consisting predominantly of approximately equal amounts of plagioclase and potash feldspar

MORAINE—an accumulation of earth, stones, etc. deposited by a glacier

MORPHOLOGY—the external structure of rocks in relation to the development of forms or topographic features produced by erosion

NEBULA—a faint misty patch of light in the heavens produced by clustered stars or by masses of diffused gaseous matter

NEOGENE—relating to or being the later portion of the Tertiary including both the Miocene and Pliocene

NERITIC ENVIRONMENT—a region of shallow water adjoining the seacoast and usually considered to extend from low-tide mark to a depth of 100 fathoms

NUMMULITE—a type of foraminifera

OLIGOCENE—noting or pertaining to the third oldest epoch of the Tertiary period of system

OPHIOLITE SUITE—association of spilites, chert and graywacke

ORDOVICIAN—the period following the Cambrian and next below the silurian

OROGENY—the process of mountain making especially by folding of the crust

PALEOCENE—of or relating to a subdivision of the Tertiary

PALEOGENE—originated in the past geologcal epoch

PALEOZOIC ERA—a grand division of geological history from the beginning of the Cambrian to the close of Permian. This was characterized by the culmination of nearly all classes of invertebrates except the insects.

PERMIAN PERIOD—pertaining to the last period of the Paleozoic era in which this system was formed; denoting a system of rocks lying beneath the Triassic rocks, and immediately above the Carboniferous system, and forming the uppermost of the Paleozoic strata

PHANEROZOIC EON—of or relating to the Paleozoic, Mesozoic, and Cenozoic eras taken together

PHYSIOGRAPHY—the description and genetic interpretation of the relief features of the earth's surface

PLANETISIMAL—a small solid body probably similar to a meteorite in composition but differing from one in that it revolves in an orbit around a central gaseous nucleus as do the planet around the sun

PLEISTOCENE—the earlier of the two epochs constituting the Quaternary period, characterized by the sedimentary and glacial deposits and fossil remains which include present day as well as much older species

PLIOCENE—the latest epoch of the Tertiary period; the strata deposited during that epoch

PLUTONIC ROCK—an igneous rock (as granite) of holocrystalline granular texture regarded as having solidified at considerable depth below the surface

PORPHYRY—an Equiptian rock consisting of feldspar crystals embedded in a compact dark red or purple groundmass much used by ancient Romans

PORPHYRY COPPER—a large low grade disseminated copper deposit

PROTEROZOIC—of or relating to grand division of geological history that includes the entire interval from the beginning of the Huronian to the close of the Keweenawan, perhaps exceeds in length all of subsequent geological time, and is marked by rocks that contain a few fossils indicating the existence of animals as highly organized as annelid worms and of blue-green and brown algae

QUARTZ—silica group of minerals

QUATERNARY—of or relating to the geological period from the end of the Tertiary to the present time

RADIOACTIVITY—the emission of radiant energy; the property, possessed by some elements (as radium, uranium, thorium and their products) whether free or combined or spontaneously emitting

alpha or beta rays and sometimes also gamma rays by the disintegration of the nuclei of atoms

RADIOLARIAN—an extensive order of rhizopods having the protoplasm divided into an inner nucleated portion enclosed in a perforated membrane of chitenlike materials

SAND BAR—a ridge of sand formed in a river or the sea by the action of tides or currents

SANDSTONE—a sedimentary rock made up of sand that usually consists of quartz more or less firmly united by some cement and that varies in color being commonly red, yellow, brown, gray or white

SCHIST—a metamorphic crystalline rock having a closely foliated structure, admitting of division along approximately parallel planes

SEISMOLOGY—a science that deals with earthquakes and attendant phenomena including the study of artificially produced elastic waves in earth materials

SHALE—a fissile rock that is formed by the consolidation of clay, mud, or silt, has a finely stratified or laminated structure parallel to the bedding, and is composed of minerals that have been essentially unaltered since deposition

SHIELD—the pre-cambrian nuclear mass of a continent around which and to some extent upon which the younger sedimentary rocks have been deposited

SILICATES—any of numerous insoluble often complex metal salts that contain silicon and oxygen in the anion, that constitute the largest chemical group of minerals

SILURIAN—part of the Paleozdic period between the Ordovician and Devonian

SPILITES—a very fine grained to dense and greenish to gray-green extrusive rock of the gabbro family

SYENITE—a variety of granite anciently quarried at Syene in Upper Egypt in which biotite is substituted for

SYNCLINES—a trough of stratified rock in which the beds dip toward each other from either side

TABIOS—the smallest commercial freshwater fish in the world

TALC—a mineral consisting of a basic magnesium tetrasilicate that is usually whitish, greenish or grayish with a soapy feel and occurs in foliated, granular or fibrous masses

TECTONIC—relating to the deformation of the earth's crust, the forces involved in or producing such deformation, and the resulting rock structure and external forms

TEKTITES—a glassy body of probably meteoritic origin and of rounded but indefinite shape found especially in the Philippines, Czechoslovakia, Indonesia and Australia

TERTIARY—of or relating to the time interval between the close of the Mesozoic era and the beginning of the Quaternary period during which the Alps, Caucasus, Himalayas, and other mountains were formed, the Cordilleran system from Alaska to Cape Horn was developing, and the dominant land life was mammalian

TETHYS—a paleographic sea (ancestral to the present Mediterranean) which coming into existence in early Permian time, connected rise the Pacific and Arktic oceans and separated the Permian continents Angara on the north from Gondavana on the south

TONGUESTONES—are marine objects with a triangular shape like tonques obtained from cliffs of Malta

TRIASSIC—of or relating to a division of the Mesozoic in which gymnosperms (as the cycads) are the most distinctive plants, the amphibians decline but the reptiles and ammonities develop rapidly, mammals probably exist but are few, small, and primitive

TRILOBITES—any of numerous extinct marine anthropods constituting the group trilobita so-called from the division of the segments of the body by furrous on the dorsal surface into three lobes, a median one and two lateral ones. They are usually of the flattened oval form and besides the longitudinal lobes, present three transverse body regions, head thorax and pygidium

TUFF—a rock composed of finer kind, of volcanic detrites, usually more or less stratified, and in various states of consolidation

ULTRAMAFIC—ultrabasic

UNIFORMITARIANISM—a geological doctrine that existing processes acting in the same manner and with essentially the same intensity as at present are sufficient to account for all geological changes

VUG—a small unfilled cavity in a lode or in rock usually lined with a crystalline layer of different composition from the surrounding rock

VOLCANISM—the quality or state of being volcanic which includes all phenomena connected with the movement of heated material from the interior to or toward the surface of the earth

VOLCANO—a vent in the earth's crust from which molten or hot rock and steam issue

YLEM—the primordial first substance from which according to some theories the elements were supposed to be formed

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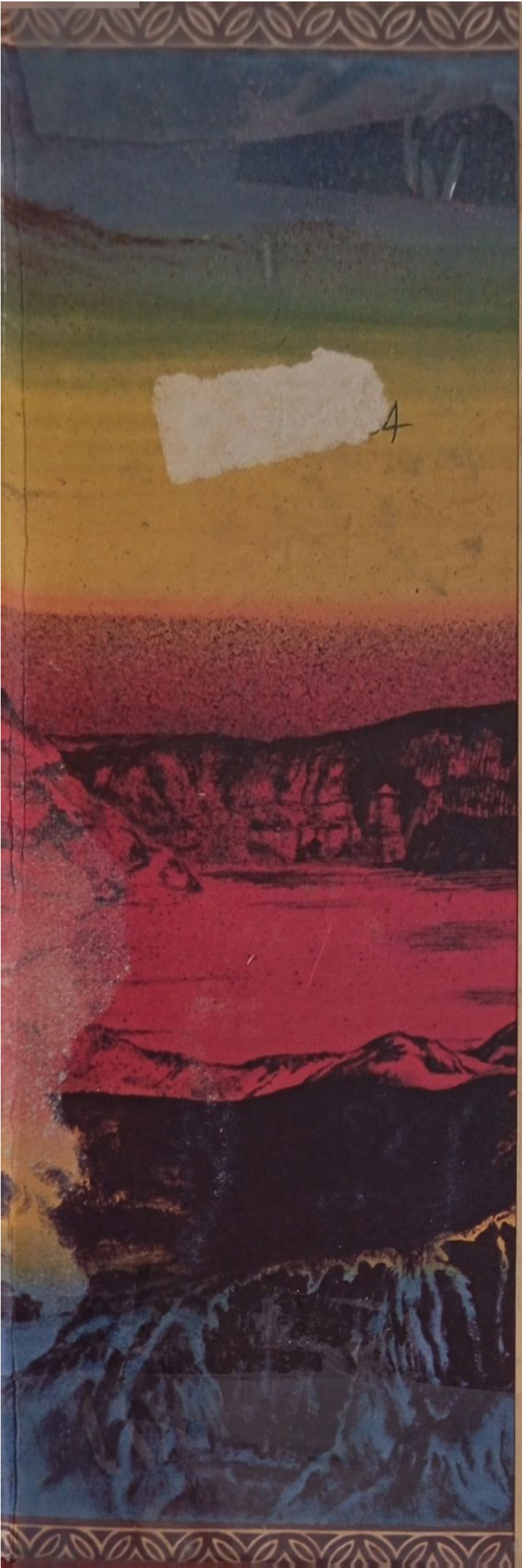

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part of our past during which no human being lived and turns it into an exciting and dramatic story. This is fortunate, after prehistory had been written about exclusively by scientists and technicians who left the subject dry as dust. But the dust of creation, the rocks and fossils, and the exceedingly slow process of evolution all constitute drama. In the hands of a writer of skill and style, [illegible] demonstrated himself to [illegible] previously published books of [illegible] history now comes to life, [illegible] examples. Until he has read this book, the average layman may not have realized that color, scent and sound characterize the story of the evolution of the universe, the earth and the Philippine archipelago; the first two, the setting of human life, the last one, the setting of Philippine history, which is what Tadhana is all about.

"Archipelagic Genesis," while dealing with the traditional epochs in the evolution of the universe, discovers their story with a historian's eye for life. It accompanies the reader on a journey through the Philippine archipelago to obtain a profile of the country consisting of the contours of land and sea, the mountain ranges, valleys, underwater ridges and trenches which have been the result of billions of years of formation, destruction and change. It gives the layman a glimpse of the complex processes of evolution, the drama of creation and the drama of growth and transformation in terms of geology, geography and the varieties of fauna and flora which preceded man's coming. Its unique value, never before seen in scientific accounts, is to make understandable to the Filipino the environment upon which his ancestors settled and in which he lives today.

FERDINAND E. MARCOS FOUNDATION, INC.

Designed by Mal[illegible]g Santos
Illustration by Edgar[illegible]

Before written records of man's social nature began to differentiate one tribe or race from another, all matter shared a faceless, volatile existence. From the mysterious 'soup' of which the early universe consisted to the hard material of the planets and finally the varieties of life, all things were bound in a common voyage through thousands of millions of years across interminable space. The notion of history came to man only when distinct differences became perceivable as particular races and communities in this huge retinue through time and space stepped off, as it were, in various directions to chart individual destinies . . .Part of this process is the formation of the setting upon which a particular national history would be laid. On the larger canvas of the universe the picture that this process evokes consists of galaxies and constellations flung here and there, perhaps by a combination of accident and physical laws, through a limitless abyss. On the lesser scale of the planet earth, the process of particularization comprises the evolution of continents and islands, the homes of various groups of men themselves slowly evolving into distinct societies... The history of the Filipino people would take place on one such distinct setting . . .